U.S. Department of the Interior
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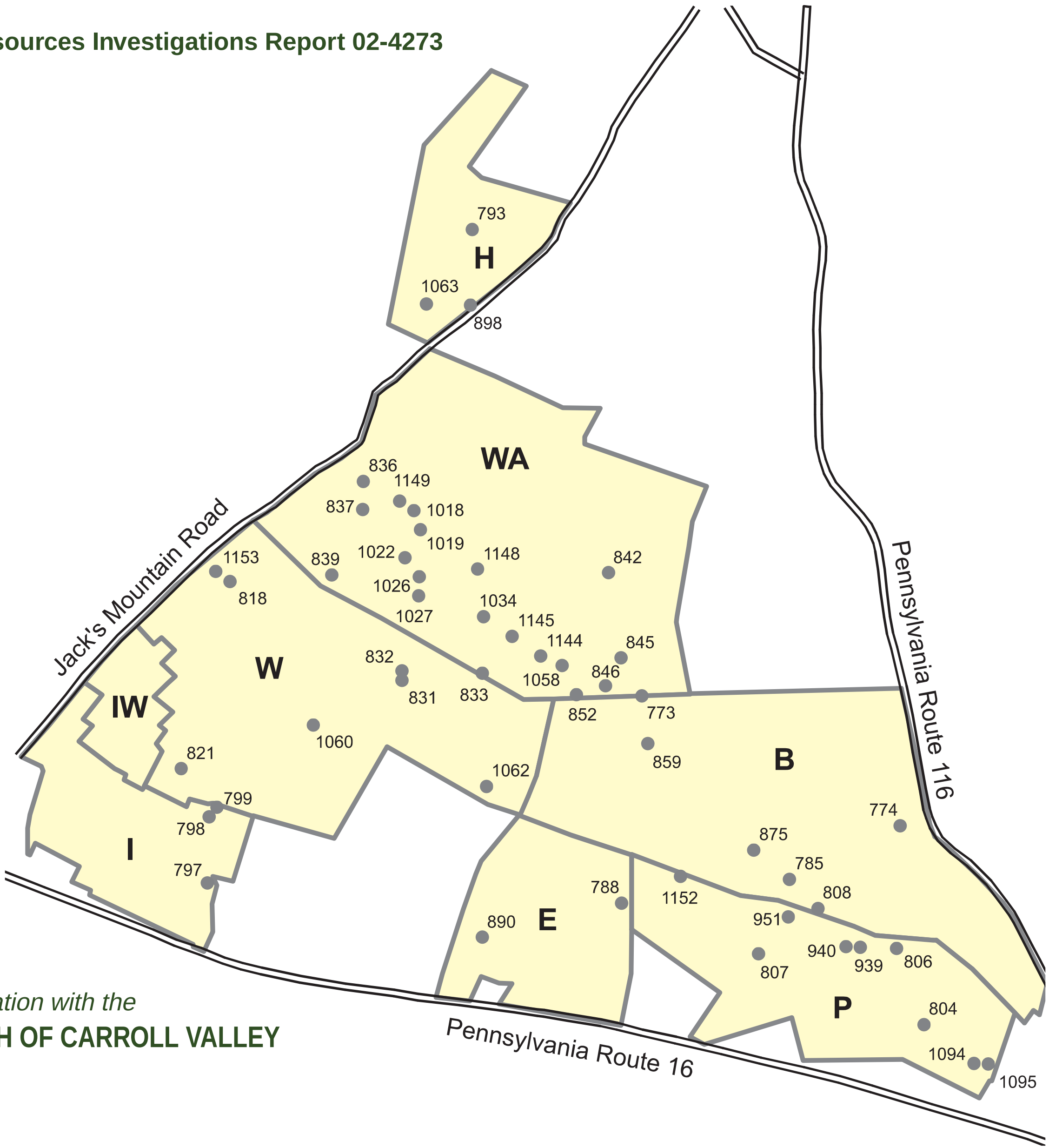
Ground-Water Availability in Part of the Borough of Carroll Valley, Adams County, Pennsylvania, and the Establishment of a Drought-Monitor Well

Water-Resources Investigations Report 02-4273



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BOROUGH OF CARROLL VALLEY

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by Dennis J. Low and Randall W. Conger

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BOROUGH OF CARROLL VALLEY

New Cumberland, Pennsylvania
2002

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information
write to:

District Chief
U.S. Geological Survey
215 Limekiln Road
New Cumberland, Pennsylvania 17070-2424
Email: dc_pa@usgs.gov
Internet address: *http://pa.water.usgs.gov*

Copies of this report may be
purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, Colorado 80225-0286
Telephone: 1-888-ASK-USGS

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CONVERSION FACTORS, DATUMS, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
	Area	
acre	4,047	square meter
square mile (mi^2)	2.590	square kilometer
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second
gallon per day (gal/d)	3.785	liter per day
gallon per day per acre [(gal/d)/acre]	0.0009353	liter per day per square meter
	Mass	
ton, short	0.9072	megagram

Temperature

Temperature conversions for degrees Fahrenheit (°F) and degrees Celsius (°C) are given in the following equations:

$$°C=5/9\ (°F-32)$$
$$°F=1.8\ °C+32$$

Multiply	By	To obtain
	Transmissivity	
square feet per day (ft^2/d)	0.0929	square meters per day
	Specific capacity	
gallon per minute per foot [(gal/min)/ft)]	0.2070	liter per second per meter
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day
	Volume	
gallon per foot (gal/ft)	12.42	liter per meter

Other Abbreviations

Abbreviated water-quality units used in this report:

- micrograms per liter (μg/L)
- microsiemens per centimeter (μS/cm)
- milligrams per liter (mg/L)
- milliliters (mL)

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83) and to the North American Datum of 1927 (NAD 27). Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

GROUND-WATER AVAILABILITY IN PART OF THE BOROUGH OF CARROLL VALLEY, ADAMS COUNTY, PENNSYLVANIA, AND THE ESTABLISHMENT OF A DROUGHT-MONITOR WELL

by Dennis J. Low and Randall W. Conger

ABSTRACT

Continued population growth in the Borough of Carroll Valley (Borough) coupled with the drought of 2001 have increased the demand for ground water in the Borough. This demand has led Borough officials to undertake an effort to evaluate the capability of the crystalline-bedrock aquifers to meet future, projected growth and to establish a drought-monitor well within and for the use of the Borough. As part of this effort, this report summarizes ground-water data available from selected sections within the Borough and provides geohydrologic information needed to evaluate ground-water availability and recharge sources within part of the Borough.

The availability of ground water in the Borough is limited by the physical characteristics of the underlying bedrock, and its upland topographic setting. The crystalline rocks (metabasalt, metarhyolite, greenstone schist) that underlie most of the study area are among the lowest yielding aquifers in the Commonwealth. More than 25 percent of the wells drilled in the metabasalt, the largest bedrock aquifer in the study area, have driller reported yields less than 1.25 gallons per minute. Driller reports indicate also that water-producing zones are shallow and few in number. In general, 50 percent of the water-producing zones reported by drillers are penetrated at depths of 200 feet or less and 90 percent at depths of 370 feet or less. Borehole geophysical data indicate that most of the water-producing zones are at lithologic contacts, but such contacts are penetrated infrequently and commonly do not intersect areas of ground-water recharge. Single-well aquifer tests and slug tests indicate that the bedrock aquifers also do not readily transmit large amounts of water. The median hydraulic conductivity and transmissivity of the bedrock aquifers are 0.01 foot per day and 2.75 feet squared per day, respectively.

The crystalline and siliciclastic (Weverton and Loudoun Formations) bedrock aquifers are moderately to highly resistant to weathering, resulting in topographic highs coupled with steep, narrow valleys. This rugged topography results in extensive surface runoff, which limits infiltration and hence recharge to the shallow and deep ground-water systems. Streams that flow through the study area generally are small and ephemeral. Where perennial, the streams represent areas of ground-water discharge.

Thickness of the overlying mantle (regolith or depth to bedrock) varies from 0 to more than 65 feet over short distances. In general, a thick regolith will store and transmit large quantities of water to the underlying bedrock aquifers. In the study area, however, there is no correlation between thick regolith and greater reported yields. Thus, it appears that the hydraulic connection between water-bearing fractures at depth and ground water stored in the regolith is poor, which further limits ground-water availability.

Recharge to the bedrock aquifers from the approximately 46 inches of annual precipitation averages about 13 inches per year, or 975 gallons per day per acre. During drought years, however, this recharge rate may average only 9 inches per year [675 gallons per day per acre]. Decreased recharge to the bedrock aquifers results in declining water levels and possibly dry wells, as well as reduced flows to streams and other surface-water bodies. Although the consumptive use of ground water by homeowners is minor (about 14 percent), the pumping of a well will change the natural flow paths of ground water and reduce the amount of water stored (at least temporarily) in the bedrock aquifers.

Potentiometric-surface maps constructed for November 2000 and August 2001 indicate that hydraulic gradients (and by inference ground-water flow paths) do not exhibit large seasonal changes. In general, ground-water flow paths are dominated by Jack's Mountain, a topographic high. This area of high hydraulic head drives ground water in a southeasterly direction to the topographically lower study area. A ridge that bisects the study area serves as a ground-water divide, directing water to Miney Branch and Toms Creek that border the study area. Ground-water levels tend to be nearer the land surface in valleys than on hilltops or slopes.

Chemical and water-quality indicators, including chloride and nitrate (as N), and the presence of coliform bacteria and wastewater compounds, suggest that ground-water recharge can be affected by anthropogenic sources such as fertilizer, road salt, and sewage. Chloride concentrations ranged from 1.3 to 35.9 milligrams per liter. Concentrations of nitrate greater than 2.0 milligrams per liter were found in water from 12 of 35 wells sampled. Total coliform bacteria was found in water from 6 of 35 wells sampled and fecal coliform bacteria in 2 of 35 wells sampled. Chloride to bromide ratios in the water from 18 wells ranged from 88 (dilute ground water) to 1,200 [ground water probably effected by anthropogenic source(s)]. A total of 6 of 67 wastewater compounds analyzed were detected in the water from the six sampled wells. Concentrations of the wastewater compounds ranged from less than 0.02 to 1.2 micrograms per liter. The most common wastewater compounds (5 of 6 wells) were DEET, Bisphenol A, triphenyl phosphate, and Phenol.

A drought-monitor well, AD-808, was established in the Borough. Well AD-808 was selected from an original network of five other wells on the basis of location, availability, and hydrologic factors. Continuous water-level data from well AD-808 exhibit typical seasonal fluctuations (declining water levels in summer, increasing water levels in winter). The water level in well AD-808 also responds rapidly to precipitation events as well as changes in evapotranspiration. The water level in well AD-808 is not influenced by nearby pumping. Water-level duration curves for the purpose of establishing well AD-808 as a drought-monitor well in the Borough were constructed by utilizing the 47 years of record for Cumberland County observation well CU-2.

INTRODUCTION

Continued population growth has increased the demand for ground water in the Borough of Carroll Valley (hereafter referred to as "Borough") (fig. 1). In 1998, more than 20 wells in the Borough went dry, forcing home owners to either deepen existing wells, drill new wells, or have water transported to their homes. To address the capacity of ground water to meet the increased demand, the U.S. Geological Survey (USGS) and the Borough began a cooperative investigation of ground water in sections B, E, H, I, IW, P, W, and WA in 2000 (fig. 2). The geohydrology, ground-water availability, ground-water flow, and the effect of drought were evaluated through the use of databases maintained by the USGS, the Pennsylvania Department of Conservation and Natural Resources Bureau of Topographic and Geologic Survey (PaGS), the Borough, and water-well driller Randy Alexander; previous studies; and field investigations. The desired outcomes of this evaluation are (1) to provide Borough officials with a better understanding of the geohydrology of the Borough and (2) to establish a drought-monitor well within the Borough.

Purpose and Scope

This report provides geologic and hydrologic information regarding the availability of ground water in selected parts of the Borough and the effect of the 2001 drought on ground-water levels. This report describes the geohydrologic (or ground-water) system and the water-bearing and water-transmitting properties of the bedrock aquifers on the basis of data from 369 wells. Potentiometric-surface maps on the basis of data from approximately 75 wells are presented. Possible anthropogenic sources of ground-water recharge are evaluated through selected (nitrate, bacteria, chloride, bromide, and wastewater compounds) ground-water chemistry data. The report also summarizes relevant geologic literature through 2001 and the establishment of a drought-monitor well within the Borough.

Acknowledgments

The authors acknowledge the cooperation of citizens and personnel from the Borough, especially John Washburn, Dick Deyo, and zoning officers Carl Bower and Howard Rodriguez, for their assistance with field work and with the planning and review of this report. The authors acknowledge the cooperation of the well owners for permitting access to their wells. The authors thank water-well driller Randy Alexander for use of his extensive database and his willingness to answer questions regarding techniques of well con-

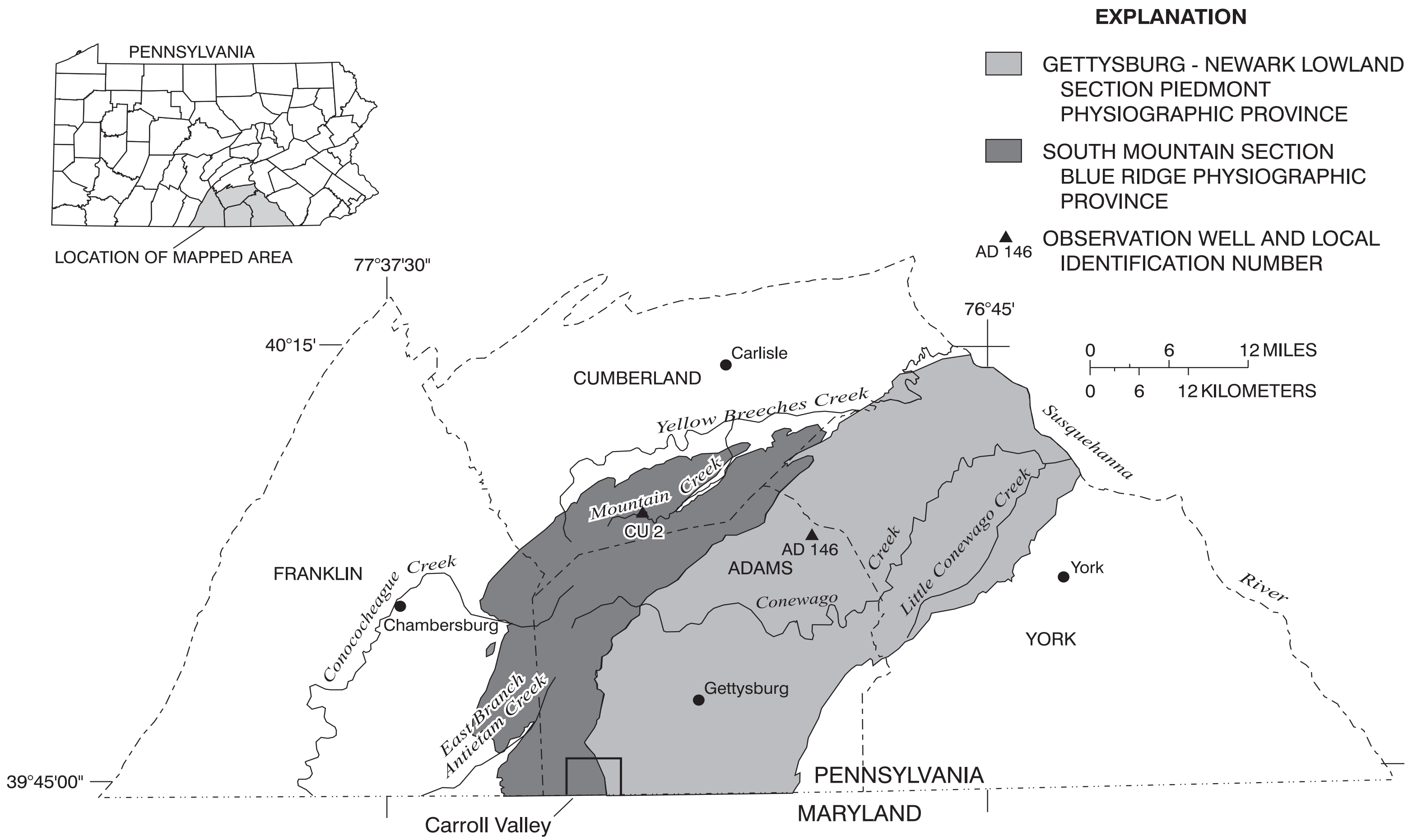
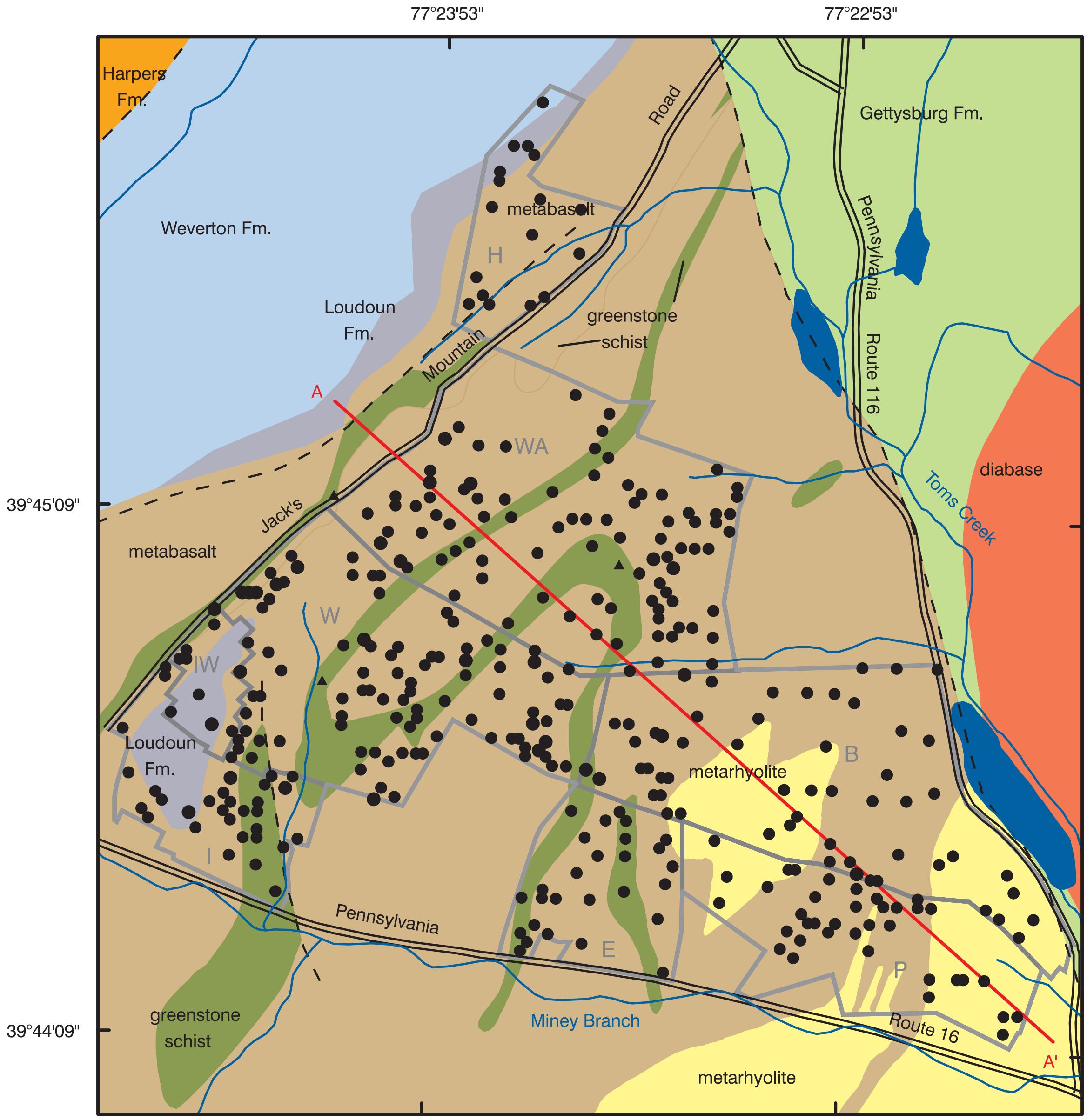


Figure 1. Location of study area, surrounding counties, physiographic provinces and sections, selected population centers, major streams, and county observation wells.



Geology from Taylor and Royer, 1981

EXPLANATION

CARROLL VALLEY SECTION BOUNDARY

FAULTS

ROADS

WELL

SPRING

A A' LINE OF SECTION

STREAMS

0 0.5 1 MILE

0 0.5 1 KILOMETER

Figure 2. Locations of inventoried wells and springs and bedrock geology, Borough of Carroll Valley, Adams County, Pennsylvania.

struction and drawdown tests. The authors also thank the members of the report-preparation team (Kevin Breen, Douglas Chichester, Denise Dumouchelle, Dennis Risser, Kim Otto); Scott Hoffman, Naomi Weisbeker, and James Bubb for their expertise and assistance in the preparation of the map and figure illustrations; and Terriann Preston and Kim Shank for their support with page layout and word processing.

Previous Work

Stose (1906, 1907, 1909, 1932), Hall (1934), and Jonas and Stose (1939) are some of the earliest authors to work at or near South Mountain. These early workers emphasized the geology, structure, and mineral resources on a county-wide scale. More recent authors such as Fauth (1968, 1978), Freedman (1967), and Root (1968, 1978) have studied South Mountain on a quadrangle-size scale. Work by Rankin and others (1969), Rankin (1976), Simpson and Sundberg (1987), Key (1991), and Root and Smith (1991) have re-examined the tectonic history of South Mountain.

Meyer and Beall (1958) and Slaughter and Darling (1962) conducted studies on aquifer properties of metarhyolites and metabasalts at South Mountain in Maryland. The transmissivities and storage coefficients derived for the metarhyolite and the metabasalt were determined from single and multiple-well aquifer tests. Trainer and Watkins (1975) working in the Upper Potomac River Basin used streamflow discharges and aquifer tests to determine the transmissivities and storage coefficients of fractured rock overlain by thin or thick regolith. The work by Taylor and Royer (1981), Low and Dugas (1999), and Low and others (2002), which summarizes the ground water of Adams County by formation and includes information on well yields and water quality, are the most extensive studies of the ground water at South Mountain currently available for Pennsylvania.

Description of Study Area

The Borough was founded in 1974 and is in south-central Pennsylvania, near the Maryland-Pennsylvania state line, occupying about 5.4 mi^2 of Adams County (fig. 1). The eastern half of the Borough lies within the Gettysburg-Newark Lowland Section of the Piedmont Physiographic Province and is underlain by reddish-brown shale, siltstone, sandstone, and an erosion resistant diabase. The western half of the Borough, which encompasses the study area (specifically sections B, E, H, I, IW, P, W, and WA), lies within the South Mountain Section, the northernmost extension of the Blue Ridge Physiographic Province (Fenneman, 1938). The rocks that underlie the study area consist of sandstone and quartzite (Weverton Formation), phyllite (Loudoun Formation), and volcanic extrusives (Catoctin Formation) (table 1; fig. 2). The topography is a series of linear, sub-parallel, ridges and valleys with a moderate to rugged expression, rising within the Borough from about 500 ft above NGVD 29 to a maximum altitude of 1,020 ft. The Weverton Formation, metabasalt, and metarhyolite form steep but stable slopes and ridges that are cut by deep, lateral valleys.

No through-going stream bisects the study area. Small streams that originate in South Mountain and border the study area include Miney Branch and Toms Creek (fig. 2). The latter are small tributaries to the Monocacy River, which lies within the Potomac River Basin.

The climate of the Borough is humid continental; precipitation is approximately 46 in. per year (Howard Rodriguez, Borough of Carroll Valley, written commun., 2002). Summer and winter mean temperatures are 25 and -1°C, respectively. Winds are predominantly from the west (Pennsylvania Department of Environmental Resources, 1979). Weather systems that affect the area generally originate in either Canada or central United States and move eastward. Most precipitation is derived from another flow pattern that originates in the Gulf of Mexico.

Over the past decade (1990-2000), the Borough was one of the fastest growing communities in the Commonwealth, with a population growth of almost 126 percent or 1,457 to 3,291 (Adams County Office of Planning and Development, written commun., 2001). In the next 10 years, the population of the Borough is expected to increase by 3 percent per year. A large segment of this growth is expected in the sections west of Toms Creek, where domestic wells are common and tap into the low yielding, crystalline-rock aquifers.

Land use in the Borough is dominated by single family homes generally on 0.5 acre wooded or cleared lots. Some agricultural land use, principally orchards, remains as well as heavily wooded or brush covered lots that are too steep to build on, have not received septic permits, or have conservation easements.

Local population centers in the vicinity of the study area include Carlisle, Chambersburg, Gettysburg, and York (fig. 1). However, it is the larger, proximal cities that have the greatest influence on the Borough. Approximately 30 percent of the Borough’s population commutes to Washington, D.C., Frederick, Md., or the greater Washington area. Another 25 per-

Table 1. *Geohydrologic-stratigraphic column, Borough of Carroll Valley, Adams County, Pennsylvania*

[ft, feet; >, greater than; gal/min, gallons per minute; (gal/min)/ft, gallons per minute per foot of drawdown; µS/cm, microsiemens per centimeter; pH, pH in standard units; ave., average; <, less than]

Age	Geologic Formation		Geologic description	Well-construction characteristics	Water-yielding properties	Quality of water
Cambrian	Weverton Formation		Highly resistant; sequence of gray to pink, quartz-rich rocks; major ridge former; 800-1,000 ft thick.	Well depths are 200 and 400 ft.	Yields are 3 gal/min. Specific capacities are <0.01 and 0.02 (gal/min)/ft.	No field-water quality available. Water should be soft, with low mineral content[1].
	Loudoun Formation		Moderately resistant; dark-gray, blue, to purple phyllite (bottom) to quartz conglomerate (top); 100-150 ft thick.	Well depths range from 120-470; ave. 274 ft. Casing lengths range from 21-90; ave. 55 ft.	Yields range from 1-30; ave. 9.9 gal/min. Specific capacities range from <0.01-0.86; ave. 0.26 (gal/min)/ft.	No field-water quality available. Water should be soft, with low mineral content[1].
Precambrian	Catoctin Formation	metabasalt	Highly resistant; green to gray, massive, fine- to medium-grained; contains veins and masses of epidote and quartz; ridge former; >1,000 ft thick.	Well depths range from 80-780; ave. 352 ft. Casing lengths range from 12-155; ave. 42 ft.	Yields range from 0-150; ave. 6.6 gal/min. Specific capacities range from <0.01-7.5, ave. 0.14 (gal/min)/ft.	Specific conductance ranges from 54-363; ave. 218 µS/cm. pH ranges from 5.1-6.3; ave. 5.7. Considerable range in mineral content and hardness; objectionable quantities of iron locally[1].
		metarhyolite	Highly resistant; light brown; weathers orange, gray, green; may contain quartz grains; ridge former; 300-400 ft thick.	Well depths range from 100-600; ave. 301 ft. Casing lengths range from 21-89; ave. 49 ft.	Yields range from 0-40; ave. 8.2 gal/min. Specific capacities range from <0.01-0.67; ave. 0.08 (gal/min)/ft.	Specific conductance ranges from 33-376; ave. 163 µS/cm. pH ranges from 6.8-7.2; ave. 6.9. Water should be soft, with low mineral content[1, 2].
		greenstone schist	Moderately hard; green to gray phyllite or schist; forms valleys and slopes; 100-150 ft thick.	Well depths range from 145-623; ave. 363 ft. Casing lengths range from 20-80; ave. 40 ft.	Yields range from 0.1-25; ave. 5.1 gal/min. Specific capacities range from <0.01-0.40; ave. 0.05 (gal/min)/ft.	Specific conductance 317 µS/cm, pH 5.5. Water should be soft, with low mineral content[1,2].

[1] Fauth (1978).
[2] Low and others (2002).

cent are retirees who have moved to the Borough but formerly worked in the greater Washington area (Carl Bower, Borough of Carroll Valley, oral commun., 2002).

Methods of Investigation

Characterization of the bedrock aquifers is based on data available from the USGS Ground-Water Site Inventory (GWSI) and PaGS Water Well Inventory (WWI) databases, the Borough, and driller Randy Alexander. The 372 inventoried wells and springs (fig. 2, table 4 (at the back of the report)) provided information on (1) well depths, (2) casing lengths, (3) regolith thickness, (4) depths to water-producing zones, (5) well yields, (6) specific capacities, (7) hydraulic conductivities, and (8) transmissivities (appendix A).

Wells were located in the field based on information and maps supplied by the Borough. Latitudes and longitudes were obtained using either a Global Positioning System (GPS) that utilized the North American Datum of 1983 (NAD 83) or by transferring the field-located wells onto existing USGS 7.5-minute topographic quadrangle maps that conform to the North American Datum of 1927 (NAD 27) or NAD 83.

The data presented in table 4 were supplemented by 14 slug tests conducted by the USGS (appendix A) and borehole geophysical logging. The slug tests consisted of rapidly dropping or removing a weighted tube of known volume and recording the displacement of water by means of an increase or decrease in water level at 10-second intervals. Borehole geophysical logging consisted of running the caliper, temperature, resistivity, natural gamma, and acoustic logs (appendix B). Heatpulse-flowmeter surveys also were conducted on the three wells logged (table B1). The caliper, temperature, resistivity, and acoustic logs were used to identify fractures as well as potential water-producing or water-thieving zones. The heatpulse flowmeter was used to determine the direction of vertical flow in nonpumping and pumping wells and to confirm the presence of water-producing or water-thieving zones. Natural-gamma logs were useful in determining subsurface geology (figs. B1-B3).

Water levels were collected from 76 wells on November 14, 2000, and 74 wells on August 15, 2001, to aid in determining ground-water flow paths. Water levels were measured by the use of electric tapes and corrected to land surface by subtracting the height of casing. For a number of lots, however, final grading of the yard was not complete, which would affect future land-surface corrections.

Water-quality samples were collected by the Borough in 1990 and 2001 for analysis of nitrate (as N) and fecal and total coliform bacteria by the Pennsylvania Department of Environmental Protection laboratory in Harrisburg, Pa. In conjunction with the 2001 sampling, the Borough also collected 54 additional water samples for further water-quality analysis by the USGS. The water samples collected for the USGS did not pass through holding tanks, water softeners, or other types of water holding or treatment. Specific conductance and well records for the 54 samples were measured and reviewed. Of the original 54 water samples, 35 were selected for analysis of chloride (Cl) at the USGS National Water Quality Laboratory (NWQL), Denver, Co. Based on the concentrations of nitrate and chloride, and the presence or absence of coliform bacteria, 18 water samples then were analyzed by NWQL for bromide (Br). A Cl:Br ratio then was determined using methods described by Jagucki and Darner (2001). On the basis of the Cl:Br ratio and the presence or absence of nitrate and coliform bacteria, six wells were revisited and sampled. The waters from these six wells then were analyzed for wastewater compounds as described by Zaugg and others (2002).

GROUND-WATER AVAILABILITY

From a hydrologic viewpoint, the availability of ground water in the Borough can be considered a house divided. East of Toms Creek in the Triassic-age rocks, ample supplies of ground water capable of meeting most domestic, commercial, and business needs are available, with the exception of areas underlain by diabase (fig. 2). West of Toms Creek, ground-water supplies may not be sufficient to meet most domestic, commercial, or business requirements, especially during drought.

The three major bedrock or crystalline-rock aquifers underlying the study area—metabasalt, metarhyolite, and greenstone schist—represent some of the lowest yielding rocks in the Commonwealth (Low and others, 2002). As a result of the low storage and transmissive properties characteristic of the crystalline-rock aquifers, many of the drilled wells in the study area are essentially a subsurface “stand pipe.” These “stand pipes” usually contain sufficient amounts of stored water to meet periods of peak domestic demand. When the well is not used, the water level will rise as ground water slowly infiltrates back into the well borehole, refilling the “stand pipe.”

The water table represents a subdued reflection of the land surface (fig. 3). The water table can be depressed by excessive pumping or reach the surface at springs and streams. Ground-water systems also can be characterized as being either shallow or deep, although most wells are open to both systems. The paths and depths of the two flow systems vary but are affected strongly by topography (ground water tends to flow from areas of higher altitude such as ridge or mountain tops to areas of lower altitude such as slopes or valleys).

The shallow system supplies ground water to the numerous small springs, streams, underlying regolith, and shallow bedrock throughout the study area and the Borough. The duration and intensity of precipitation has an almost immediate effect on the shallow system by raising static water levels and increasing

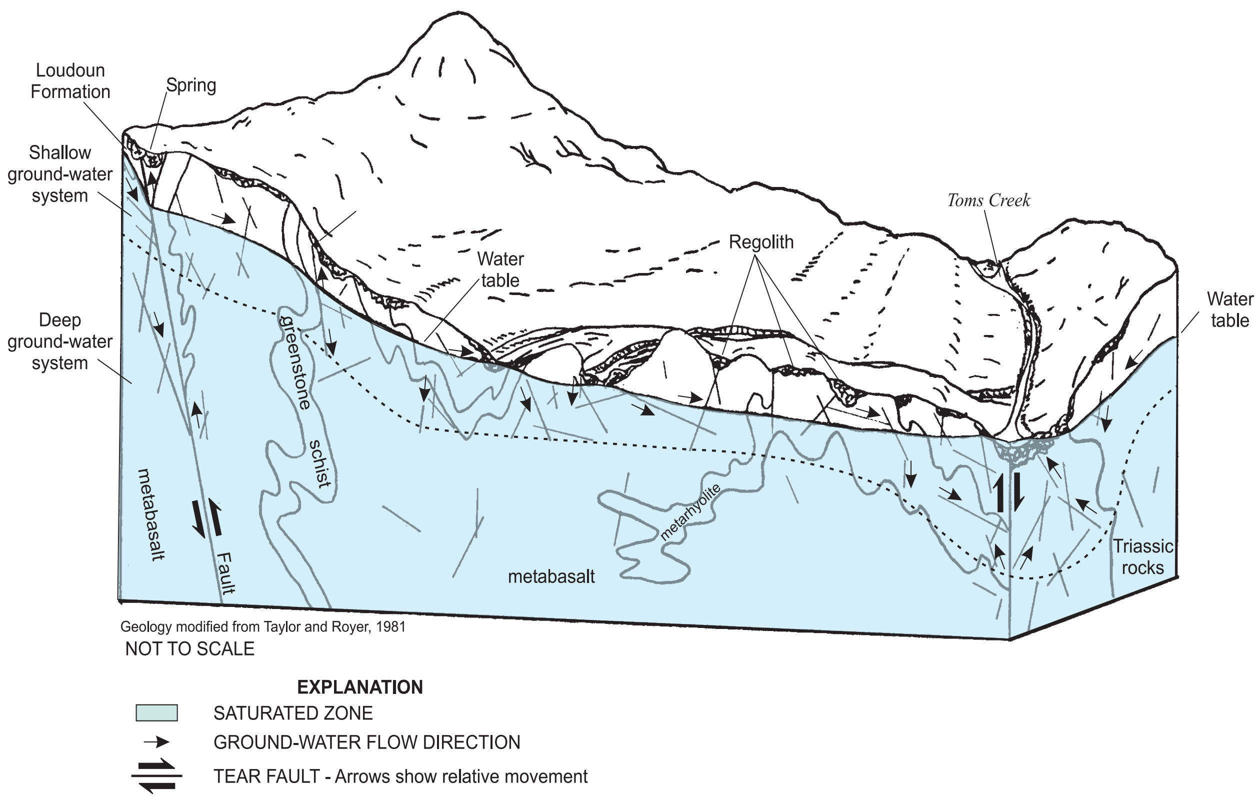


Figure 3. Topographic, hydrologic, and geologic features, Borough of Carroll Valley, Adams County, Pennsylvania.

ground-water discharge to springs and other surface-water bodies. The shallow system is connected to the deeper system through the regolith and bedrock by way of secondary openings such as fractures, joints, and cleavage planes.

The deeper system is characterized by longer, more irregular flow paths and greater residence times. Faults, such as the one that follows Jack's Mountain Road, may act as ground-water barriers, redirecting ground-water flow and causing substantial differences in water levels. The deeper system supplies the water (base flow) that sustains such surface-water bodies as Toms Creek, Miney Branch, and other streams between precipitation events and during drought.

Ground-water availability is related to human activities (casing length and well depth, onlot septic systems, impermeable surfaces), geohydrologic properties of the underlying aquifers, proximity to recharge boundaries, and precipitation. In the Borough, pumping a well and recycling this water back through the onlot septic system change the natural ground-water flow paths, but results in very little consumptive use. Watering of vegetation, however, results in a much larger consumptive use of ground water, mainly through evapotranspiration (U.S. Geological Survey, 1999b). The increase of nonpermeable surfaces such as houses, driveways, and streets increases surface runoff while decreasing infiltration into the underlying aquifers.

The rugged topography and highly resistant nature of the crystalline-rock aquifers result in large amounts of surface runoff and reduced infiltration. Ground-water recharge and availability are further limited by the clays that form as a result of bedrock weathering and the small number of secondary openings or water-bearing zones penetrated during the well drilling process.

The major source of ground-water recharge is precipitation. Over the past 9 years, the Borough has received about 46 in. of precipitation per year. In 2001, however, the Borough received about 31 in., a deficit of 15 in. or 33 percent. This significant reduction in precipitation has decreased the availability of ground water throughout the Borough for domestic usage as well as recharge to streams or base flow. The reduction in precipitation also placed additional stresses on the bedrock aquifers, resulting in a decrease in ground-water storage.

Characteristics of a Bedrock Well

Characteristics of a bedrock well (fig. 4) are most strongly affected by rock type. Rock type affects the amount of casing and well depth used in the construction of a well. Rock type also affects well yield. The rocks underlying the study area are moderately to highly resistant to weathering. This results in topographic highs such as ridges and mountain tops and narrow, but steep valleys. In general, wells in valleys require more casing but tend to have higher yields than those on slopes and hilltops. Valleys and upland draws form where the bedrock is most susceptible to physical or chemical weathering, due largely to the existence of fractures. This increased weathering results in a greater depth to bedrock. Valleys and upland draws are also low points through which upslope water (ground and surface water) must pass through or drain and, therefore, have the capability for transmitting greater amounts of water per unit volume of rock than topographically higher positions.

The depth and yield of a well is affected directly by the size and distribution of water-producing zones open to the well. In the study area, water-producing zones can occur at the contact between different rock types or other fractures. Faults, however, do not appear to be particularly transmissive (permeable). Because of the highly resistant, massive, and competent nature of the bedrock, water-producing zones in the study area do not appear to be abundant, productive, or interconnected. As a result, many wells are deep, subsurface stand or storage pipes. Secondary development, such as hydrofracturing, may increase the yield to the well by enlarging (shattering) a water-producing zone or by cleaning out clay, silt, and other debris that hinders flow to the well.

Well-construction regulations also can be an important factor that determines casing length, well depth, and well yield (fig. 4). The Borough has established regulations that must be met in order to maintain minimum standards for quality of water and yield (Howard Rodriguez, Borough of Carroll Valley, oral commun., 2002). The Borough requires (1) the source of supply shall be at a minimum of 100 ft distant from potential sources of pollution (such as a septic tank or leach field), (2) the use of watertight casing, (3) the annular space must be filled completely with an approved grouting material (such as concrete grout or bentonite), and (4) a minimum reported yield of 4 gal / min. If the yield is less than 4 gal / min, the driller must further evaluate the yielding and storage capability of the well by placing within the well a pump and measuring the volume discharged plus the amount

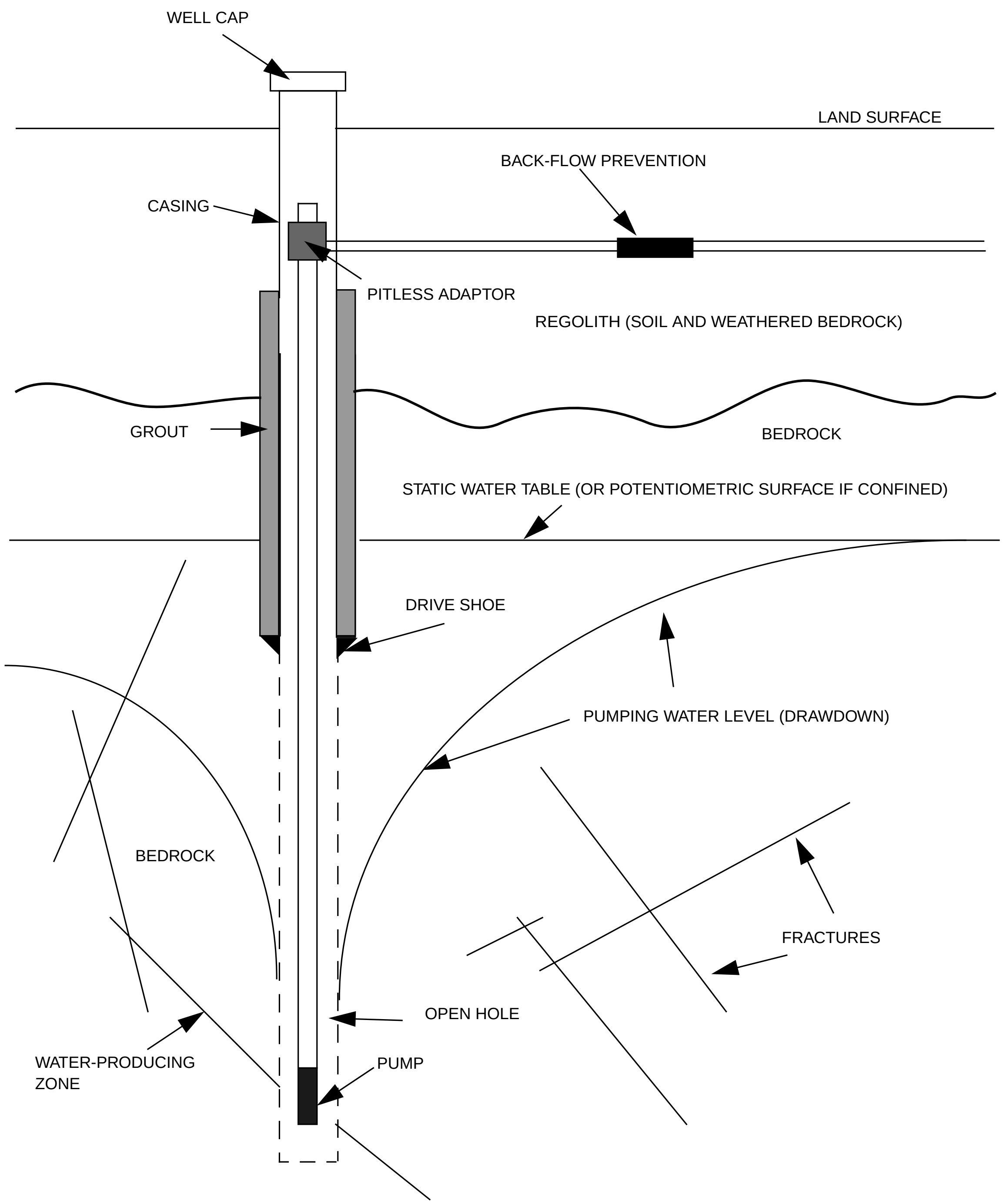


Figure 4. Cross-section of a bedrock well.

and rate of decline in the water level. If the well fails to meet the Borough requirements, a second well must be drilled, or the existing well can undergo secondary development to increase the yield. If the second well fails to meet the minimum discharge requirement of the Borough or the combined yields of both wells fail to meet the minimum requirement, the property is considered unsuitable for development and remains empty.

Casing Length

Casing lengths generally are related to the resistance to weathering of the geologic formation, the thickness of surficial deposits (regolith), regulatory requirements, and driller preference. Casing length can also serve as a surrogate for driller reported depth to rock (Low, 1992). Casing (fig. 4) is installed through the soil and weathered bedrock and must extend to a depth of at least 20 ft, with an additional 10 ft of casing extending into bedrock (Carl Bower, Borough of Carroll Valley, oral commun., 2002). Casing lengths for wells in the study area are presented in the following table. Casing lengths are slightly greater in the Loudoun Formation and metarhyolite than in the other rock types. This also holds true if topographic expression, such as slope, is considered. Casing length also may affect well yield by sealing out not only surface water infiltration but also shallow, productive water-producing zones.

Casing lengths by geologic formation

[Depth to bottom of casing, in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Geologic formation	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Weverton Formation	2	—	—	86	—	—	52	120
Loudoun Formation	9	—	25	63	74	—	21	90
metabasalt	263	21	27	40	53	63	12	155
metarhyolite	29	27	40	47	60	77	21	89
greenstone schist	47	21	28	40	42	64	20	80

Depth to bedrock or regolith thickness is highly varied, ranging from 0 to 115 ft (median is 28 ft). In many geologic terranes, thickness and composition of the regolith play an important role in providing water to a well. Regolith commonly absorbs and stores precipitation, then, over time, this stored water is slowly released to the underlying bedrock aquifer(s) and eventually to the well. A thick regolith, therefore, is capable of storing and transmitting greater quantities of water than a thin regolith. There does not, however, appear to be any significant correlation between regolith thickness and well yield. This may be the result of Borough requirements for casing length, the amount of clay produced when the crystalline rocks weather, poor connection between secondary openings in the bedrock and the overlying regolith, or other unknown factors. Depth to bedrock does change rapidly over very short horizontal distances, but does not appear to follow a recognizable pattern (fig. 5). As shown in the table below, depth to bedrock does vary by geologic formation. Depth to bedrock tends to be less in areas underlain by the metabasalt and greenstone schist. Topographic lows, such as valleys and upland draws, generally are assumed to be zones of either structural or lithologic weakness. This weakness would tend to favor a greater depth to bedrock because more rock volume would be exposed to the effects of precipitation, which enhances physical and chemical weathering. Depth to bedrock does not appear to vary greatly by topographic setting.

Depth to bedrock by geologic formation

[Depth to bedrock, in feet; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Geologic formation	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Weverton Formation	2	—	—	83	—	—	40	115
Loudoun Formation	9	—	10	48	63	—	4	108
metabasalt	251	6	10	28	40	55	0	110
metarhyolite	29	10	30	35	50	66	8	77
greenstone schist	43	10	16	25	31	57	5	65

Well Depth

Well depth is related directly to the depth and yield of water-producing zones (fig. 4). If an insufficient yield is obtained, the well driller will continue deepening the well until sufficient water is encountered or the well has sufficient storage capacity to meet most needs of the homeowner. Depths of wells in the study area are presented in the following table. Wells drilled in the metabasalt and greenstone schist generally are completed at greater depths than in the other rock types. However, the thickness of the greenstone schist and Loudoun Formation are only estimated as

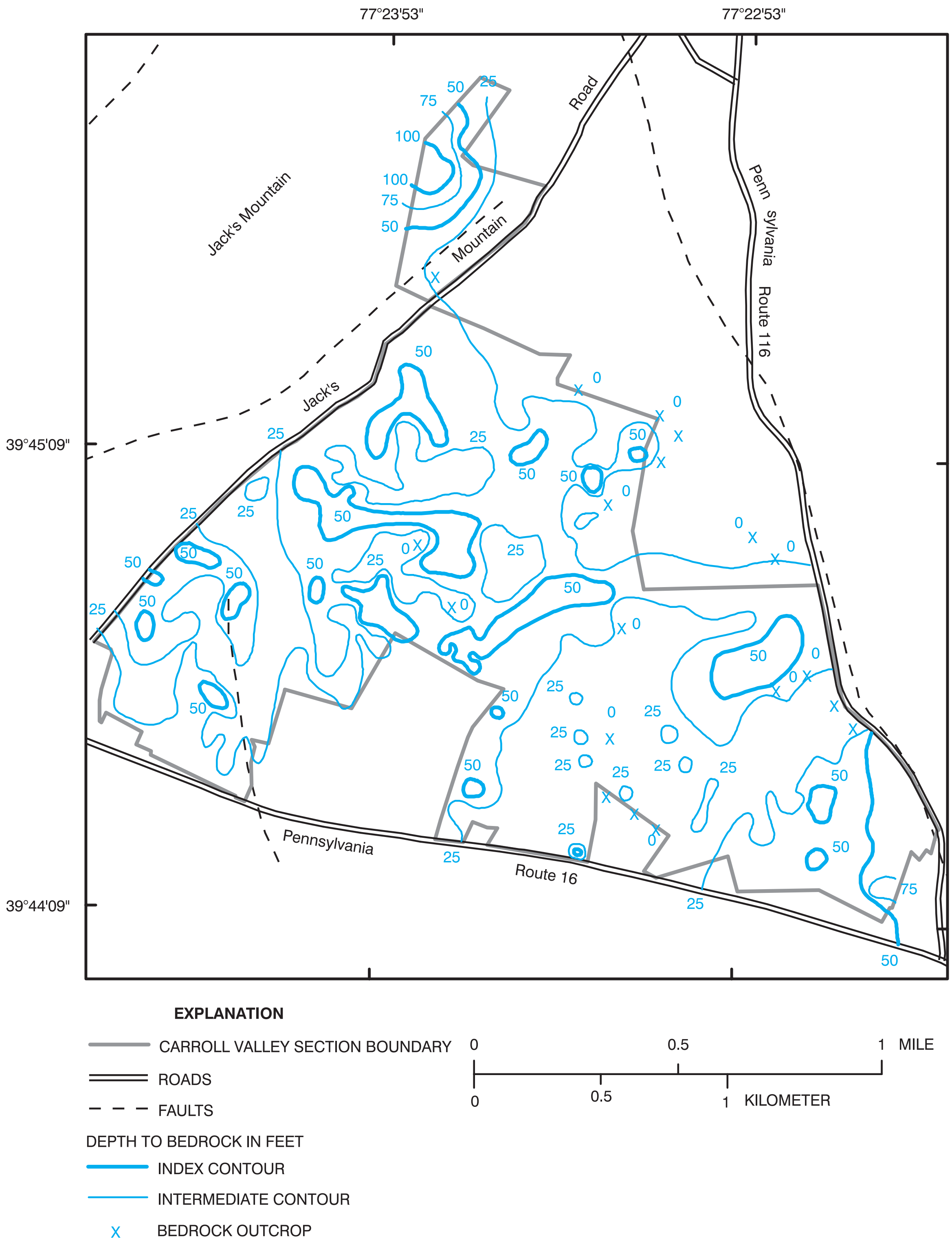


Figure 5. Depth to bedrock, Borough of Carroll Valley, Adams County, Pennsylvania.

100 to 150 ft (table 1). This indicates that most wells started in the greenstone schist or Loudoun Formation probably are completed in the underlying bedrock unit, which is predominantly metabasalt.

Driller reported depths of drilled wells by geologic formation

[Depth, in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Geologic formation	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Weverton Formation	2	—	—	300	—	—	200	400
Loudoun Formation	9	—	160	275	400	—	120	470
metabasalt	268	180	240	320	460	560	80	780
metarhyolite	30	150	210	300	340	500	100	600
greenstone schist	48	207	280	320	405	600	145	623

Topographic setting also can affect well depth. The depths of wells drilled in the metabasalt are greater if the well is on a hilltop (87 wells) than on a slope (153 wells) or an upland draw (158 wells); the median depths are 395, 300, and 302 ft, respectively.

Water-Producing Zones

Ground water in the bedrock aquifers is stored in and moves through a network of secondary openings commonly called water-bearing or water-producing zones. These secondary openings include joints, faults, cleavage planes, and fractures. Although fractured bedrock may have a low porosity, the permeability of secondary openings can be quite high. The water-producing zones presented in table 4 and figures 6 through 9 are from driller completion reports. Depths of water-producing zones are sometimes best guesses because some zones may be plugged with mud, silt, and debris as a result of drilling. The mud, silt, and debris can be removed by further drilling, by the later introduction of water in the borehole, by secondary enhancement, or continued use by the well owner. In addition, water-producing zones that yield small amounts of water may not be noticed by the driller if a shallower zone produced a considerably greater volume of water.

The distribution of 533 water-producing zones in 327 wells up to 780-ft deep were analyzed using the following criteria:

Footage Sampled

If there is a reported water-producing zone behind casing, the analysis omits from consideration footage above the reported water level.

If the first reported water-producing zone is at or below the casing, then (a) if the water level is below the casing, footage above the water level is omitted, (b) if the water level is within the cased depth, footage within the casing is omitted.

To achieve this, the excluded depth is set to the water level, and changed to the casing depth only if the first water-producing zone reported is below and the water level is above the casing.

Water-Producing Zones Counted

All water-producing zones reported are counted in the interval that they occur in, whether or not considered in footage sampled. For example, if casing is exactly 50 ft, and the water-producing zone is exactly 50 ft, one water-producing zone is counted in the interval 0 to 50 ft, but the footage sampled is zero.

Missing Data

If well depth is missing, it is set to the value of the last reported water-producing zone.

If water level and casing depth are both missing, both are set to 50.0001 ft.

If water level or casing depth is missing, the missing one is set to the given one.

Density of Water-Producing Zones

The density of the water-producing zones was determined as follows:

$$N \times 50\text{-ft} / F \qquad (1)$$

where N is equal to the number of driller reported water-producing zones per 50-ft of hole depth, and F is equal to footage of hole sample.

For example, if N equals 1 and footage of hole sample equals 223, the density of the water-producing zone per 50-ft of hole depth is 0.22.

The number and density of water-producing zones in four of the five bedrock aquifers underlying the study area are shown in figures 6 through 9. The Weverton Formation was excluded from the figures because only two water-producing zones were encountered in two wells. The depths of water-producing zones in the two wells drilled in the Weverton Formation are 120 and 135 ft below land surface.

The depths of water-producing zones in nine wells drilled as deep as 470 ft in the Loudoun Formation range from 70 to 400 ft below land surface (fig. 6). Fifty percent of the 15 water-producing zones reported are penetrated at depths of 140 ft or less and 90 percent at depths of 373 ft or less. The greatest density of water-producing zones (0.75 per 50 ft of well depth) is from 51-100 ft below land surface. The density of water-producing zones from 151 ft or greater are based on the presence of two or fewer water-producing zones per 50-ft interval. The overall density of water-producing zones in the Loudoun Formation is 0.41 per 50 ft of well depth.

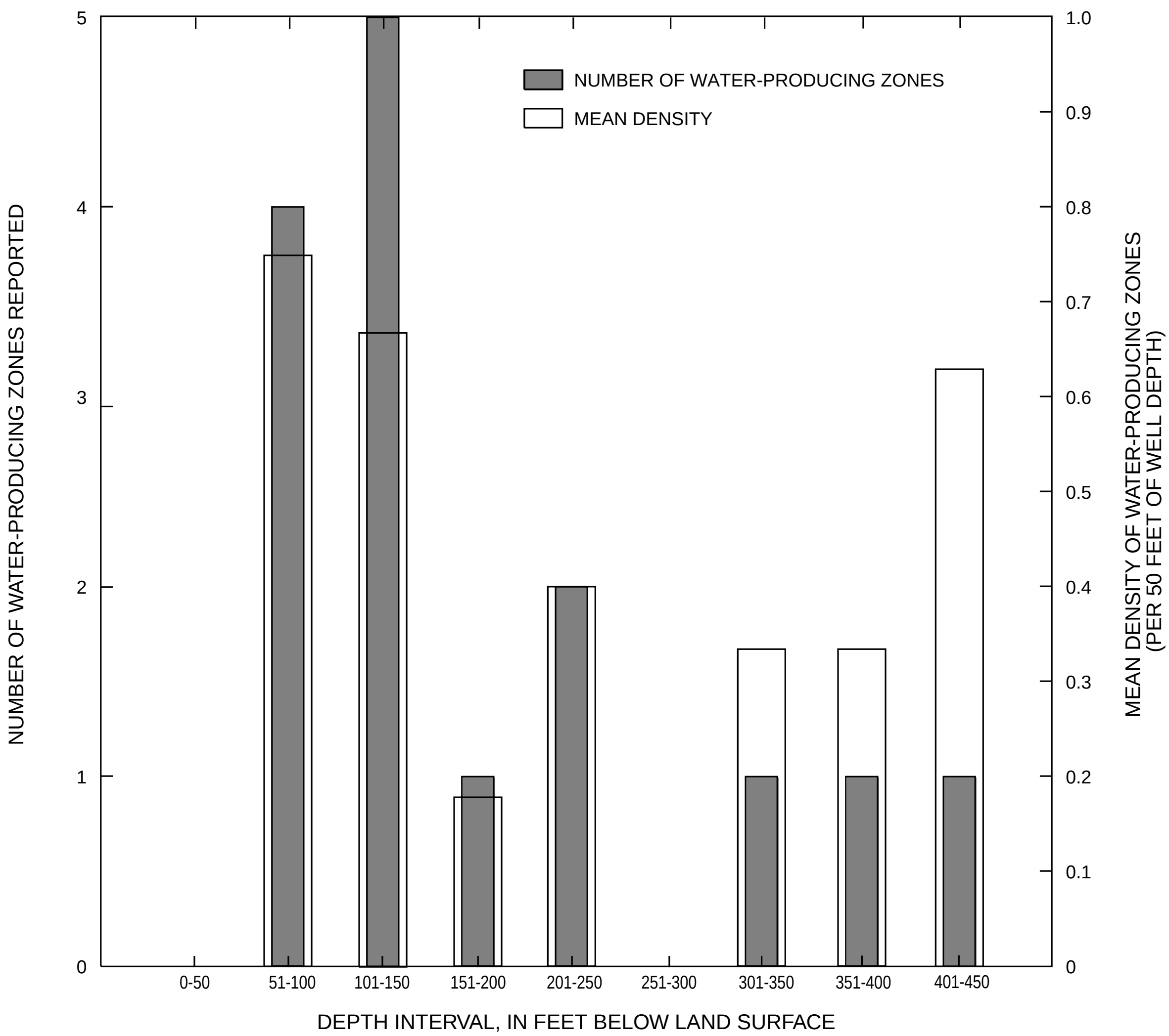


Figure 6. Number and density of water-producing zones per 50 feet of well depth in the Loudoun Formation, Borough of Carroll Valley, Adams County, Pennsylvania.

The depths of water-producing zones in 245 wells drilled as deep as 780 ft in the metabasalt range from 40 to 640 ft below land surface. Fifty percent of the 410 water-producing zones reported are penetrated at depths of 200 ft or less and 90 percent at depths of 371 ft or less (fig. 7). The greatest density of water-producing zones (0.36 per 50 ft of well depth) is from 101-150 ft below land surface. The density of water-producing zones from 501 ft or greater are based on the presence of four or fewer water-producing zones per 50-ft interval. The overall density of water-producing zones in the metabasalt is 0.29 per 50 ft of well depth.

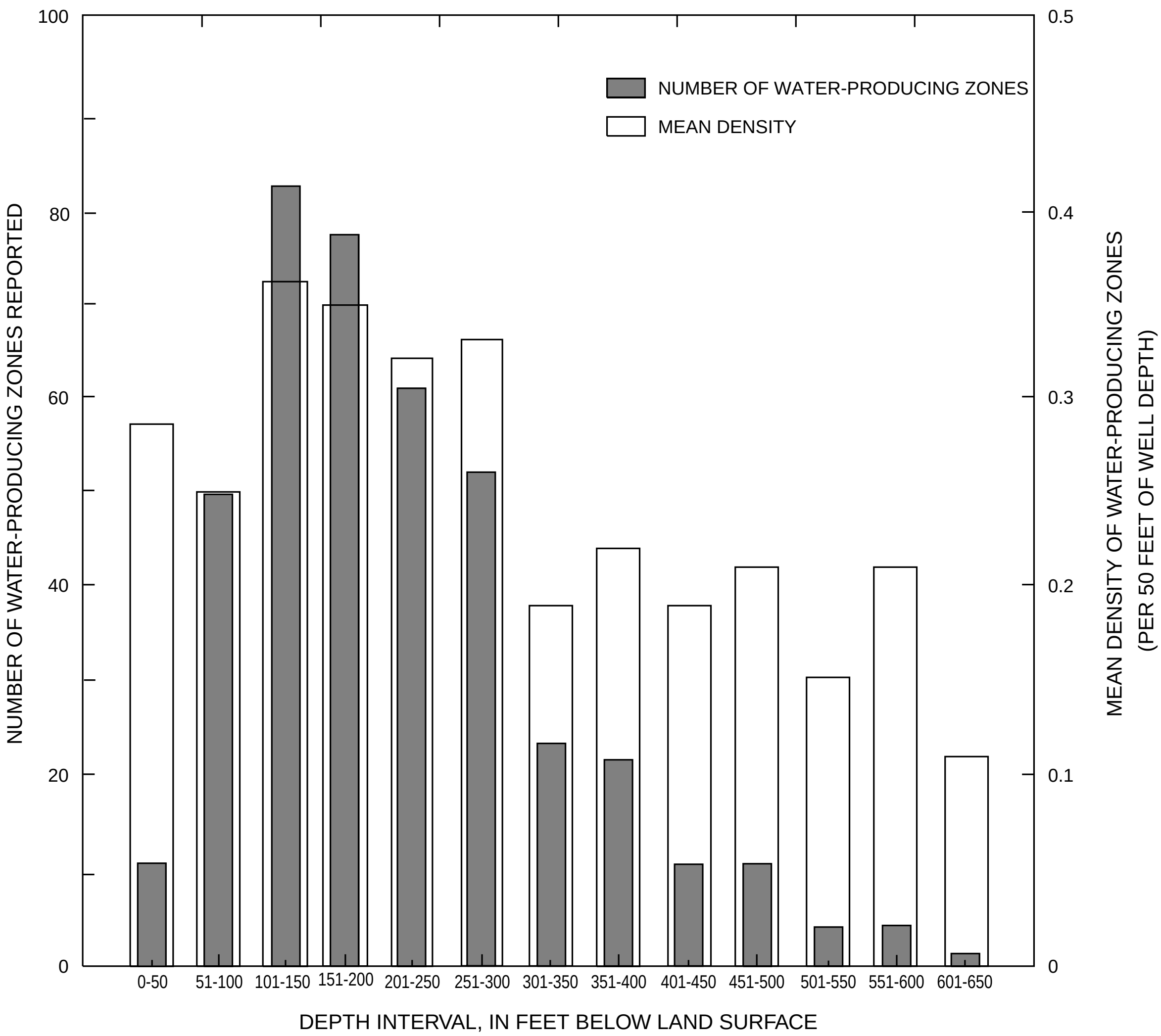


Figure 7. Number and density of water-producing zones per 50 feet of well depth in the metabasalt, Borough of Carroll Valley, Adams County, Pennsylvania.

The depths of water-producing zones in 27 wells drilled as deep as 500 ft in the metarhyolite range from 60 to 370 ft below land surface. Fifty percent of the 44 water-producing zones reported are penetrated at depths of 159 ft or less and 90 percent at depths of 300 ft or less (fig. 8). The greatest density of water-producing zones (0.73 per 50 ft of well depth) is from 51-100 ft below land surface. The density of water-producing zones from 301 ft or greater are based on the presence of three or fewer water-producing zones per 50-ft interval. The overall density of water-producing zones in the metarhyolite is 0.38 per 50 ft of well depth.

The depths of water-producing zones in 44 wells drilled as deep as 623 ft in the greenstone schist range from 60 to 520 ft below land surface. Fifty percent of the 62 water-producing zones reported are penetrated at depths of 240 ft or less and 90 percent at depths of 415 ft or less (fig. 9). The greatest density of water-producing zones (0.43 per 50 ft of well depth) is from 251-300 ft below land surface. The density of water-producing zones from 301 ft or greater are based on the presence of four or fewer water-producing zones per 50-ft interval. The overall density of water-producing zones in the greenstone schist is 0.25 per 50 ft of well depth.

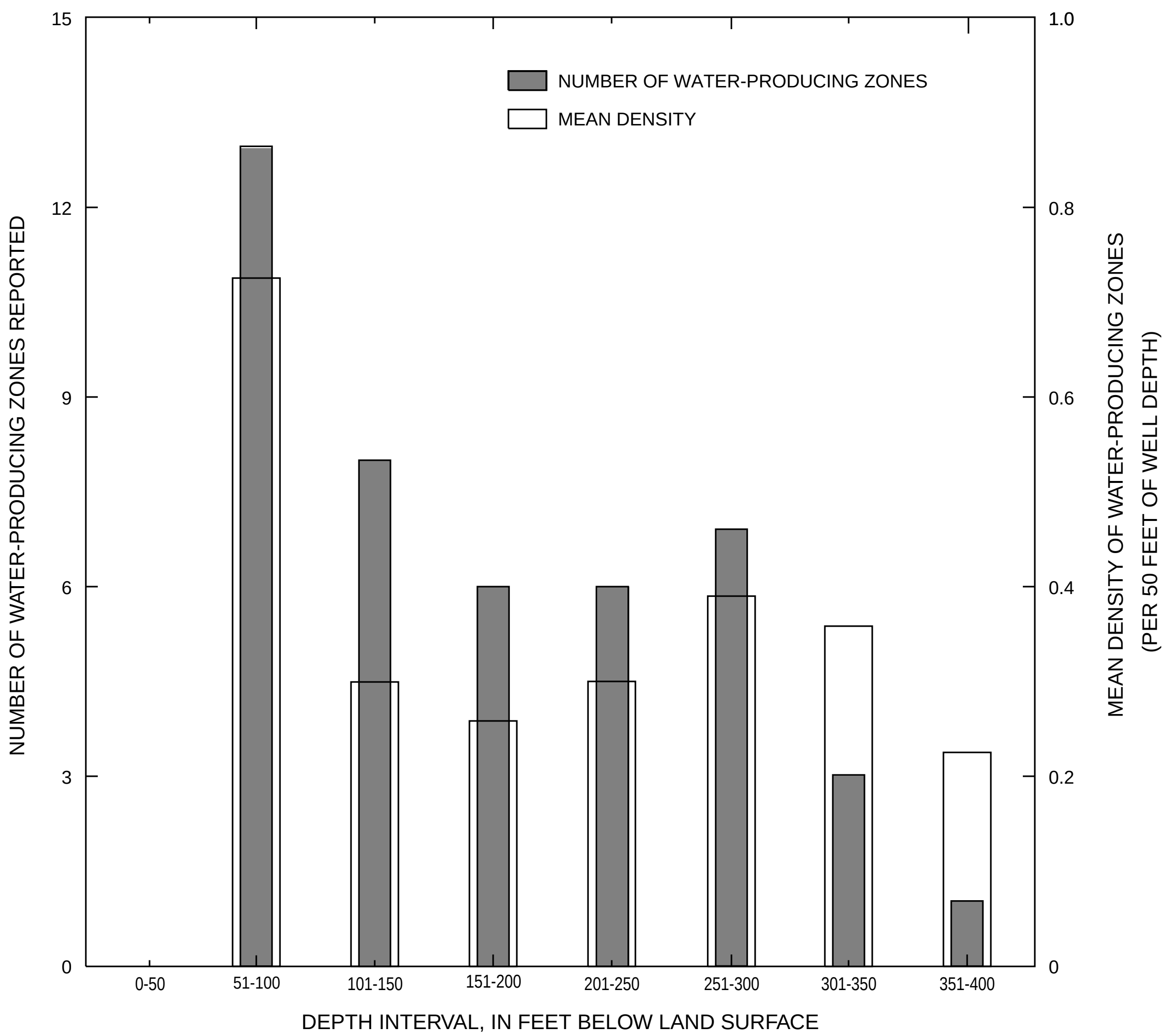


Figure 8. Number and density of water-producing zones per 50 feet of well depth in the metarhyolite, Borough of Carroll Valley, Adams County, Pennsylvania.

In many cases, it is difficult to determine if water-producing zones are connected to adjacent wells; however, there are some indications of such connections. During the drilling of a well in Section W, two adjacent homeowners with established wells reported a considerable decrease in the level of water in their wells. A third established well, about 200 ft west of the Section W well, exhibited a dramatic increase in the amount of mud, silt, and other particulates in the water. This increase of mud, silt, and other particulates is believed to be the result of developing the Section W well (Carl Bower, Borough of Carroll Valley, oral commun., 2002). For another example of fracture interconnection between wells, well AD-1152 was being monitored during the drilling of a new well approximately 150 ft to the northeast in Section B. During pumping and hydrofracturing of the new well in Section B, the water level in well AD-1152 decreased approximately 5 ft and had not recovered after 4 days of rest.

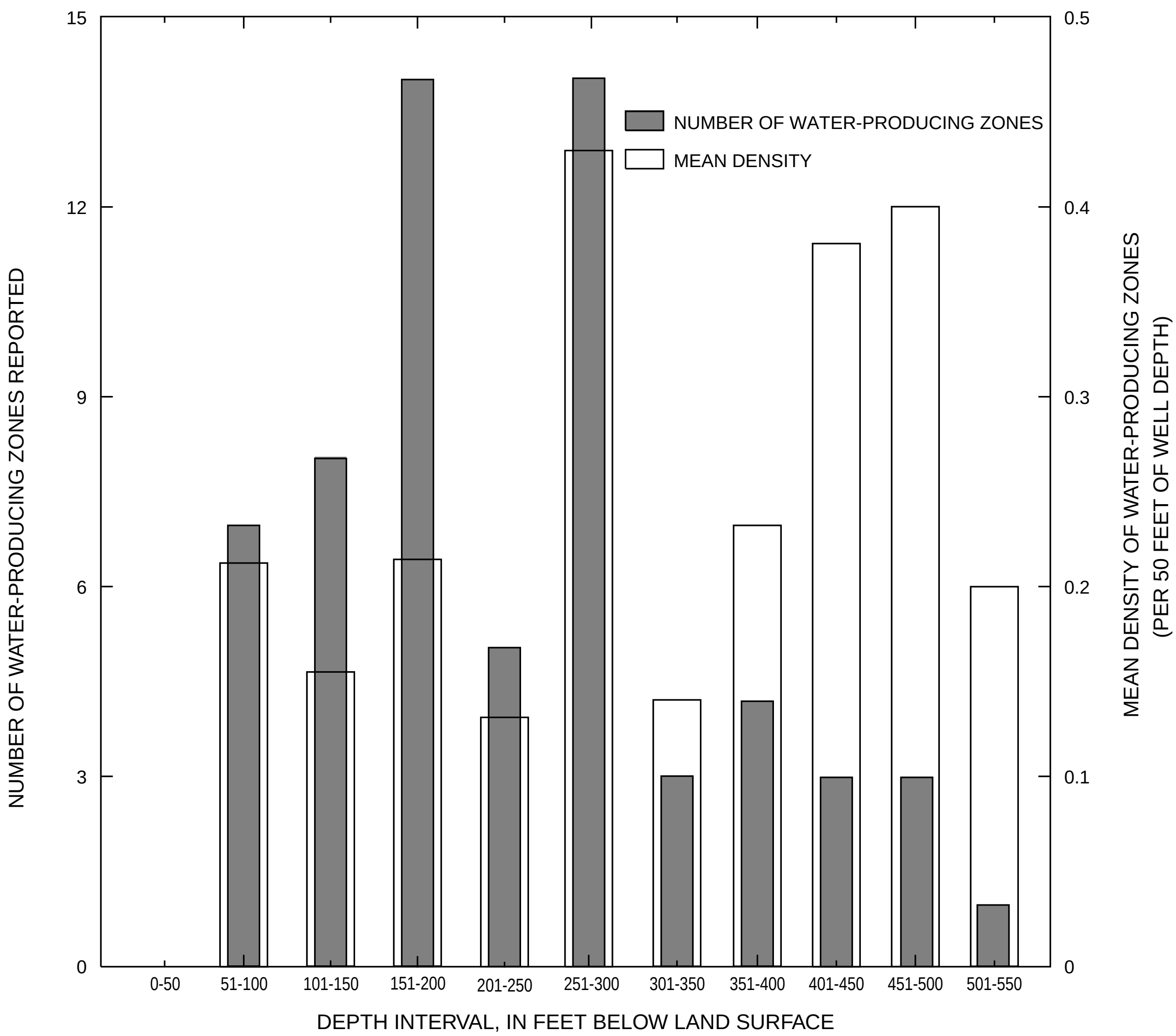


Figure 9. Number and density of water-producing zones per 50 feet of well depth in the greenstone schist, Borough of Carroll Valley, Adams County, Pennsylvania.

Discharge

The discharge (yield and specific capacity) reported or measured by a driller is affected by well construction (casing length, borehole diameter, well depth), pumping rate, and physical characteristics of the aquifer (thickness and type of regolith, size, number, and inter-connectedness of water-producing zones). A large amount of casing may reduce the discharge of a well by sealing off shallow, productive water-producing zones. The discharge of a well will increase if the diameter of the borehole increases (more surface area exposed to water-producing zones). Deep wells have greater storage capacity than shallow wells and can be pumped harder (greater reported yield) than shallow wells, although this will result in a lower specific capacity. A thick, highly permeable regolith can increase the discharge of a well by acting as a water reservoir and providing this water to a well through a network of secondary openings (water-producing zones).

The majority of yields and specific capacities (table 4) analyzed are from short-term driller completion tests during which the driller blew water (using air pressure to force water up and out of the borehole) from the well. Although this method is not as accurate as those conducted using submersible pumps and metering the discharge, it provides a reasonable basis for estimating and comparing the discharge and hydrologic properties [hydraulic conductivity and transmissivity (appendix A)] of individual geologic formations.

Yield

Yield is the volume of water per unit of time removed from a well and usually is determined by blowing the well or by pumping a well. Yield is commonly an estimated, not a measured, value and is reported in gallons per minute. Yield typically varies by rock type and topographic setting. As shown in the following table, the Loudoun Formation is the best yielding bedrock aquifer; the median reported yield is 5.0 gal / min. The metabasalt is typically the lowest yielding bedrock aquifer; the median reported yield is 3.0 gal / min. It is also interesting to note that more than 25 percent of the wells drilled in the metabasalt have yields less than 1.25 gal / min, the Borough's current (2002) minimum required yield.

Driller reported yields of drilled wells by geologic formation

[Yield, in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Geologic formation	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Weverton Formation	2	—	—	3.0	—	—	3.0	3.0
Loudoun Formation	9	—	3.0	5.0	18	—	1.0	30
metabasalt	262	0.6	1.0	3.0	7.0	14.6	.0	150
metarhyolite	29	.9	1.6	4.5	14.3	20	.0	40
greenstone schist	49	.8	1.5	3.0	6.0	15	.1	25

Topographic setting also can affect yield. As shown in the following table, wells drilled in the metabasalt and in upland draws generally have greater yields than wells drilled on slopes or hilltops. For the greenstone schist, however, yields tend to be lower in upland draws.

Driller reported yields by topographic setting for wells drilled in the metabasalt and greenstone schist

[Yield, in gallons per minute; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
metabasalt								
Hilltop	85	1.0	1.5	3.0	7.0	15	0.0	20
Slope	150	.5	1.0	2.0	6.0	10	.0	150
Upland draw	26	.8	2.5	6.0	14.5	20	.0	50
Valley	3	—	—	1.0	—	—	1.0	8.0
greenstone schist								
Hilltop	7	—	1.5	1.8	2.8	—	1.0	20
Slope	36	.5	1.5	3.2	6.0	11.5	.1	25
Upland draw	6	—	—	3.0	—	—	1.0	15

The location of relatively higher yielding wells does not appear to follow a recognizable pattern (fig. 10). Wells that yield more than 5 gal / min are dispersed randomly among wells with considerably lower yields.

Well-development techniques can increase yields beyond those obtained through typical well development (Driscoll, 1986, p. 528-533). Some methods that can be employed include acid or explosives (Driscoll, 1978), but there are many legal and safety concerns involved with these two methods. Hydrofracturing, which involves injecting fluids at high pressure into newly opened fractures, may need a propping agent such as sand to keep fractures open over time. This

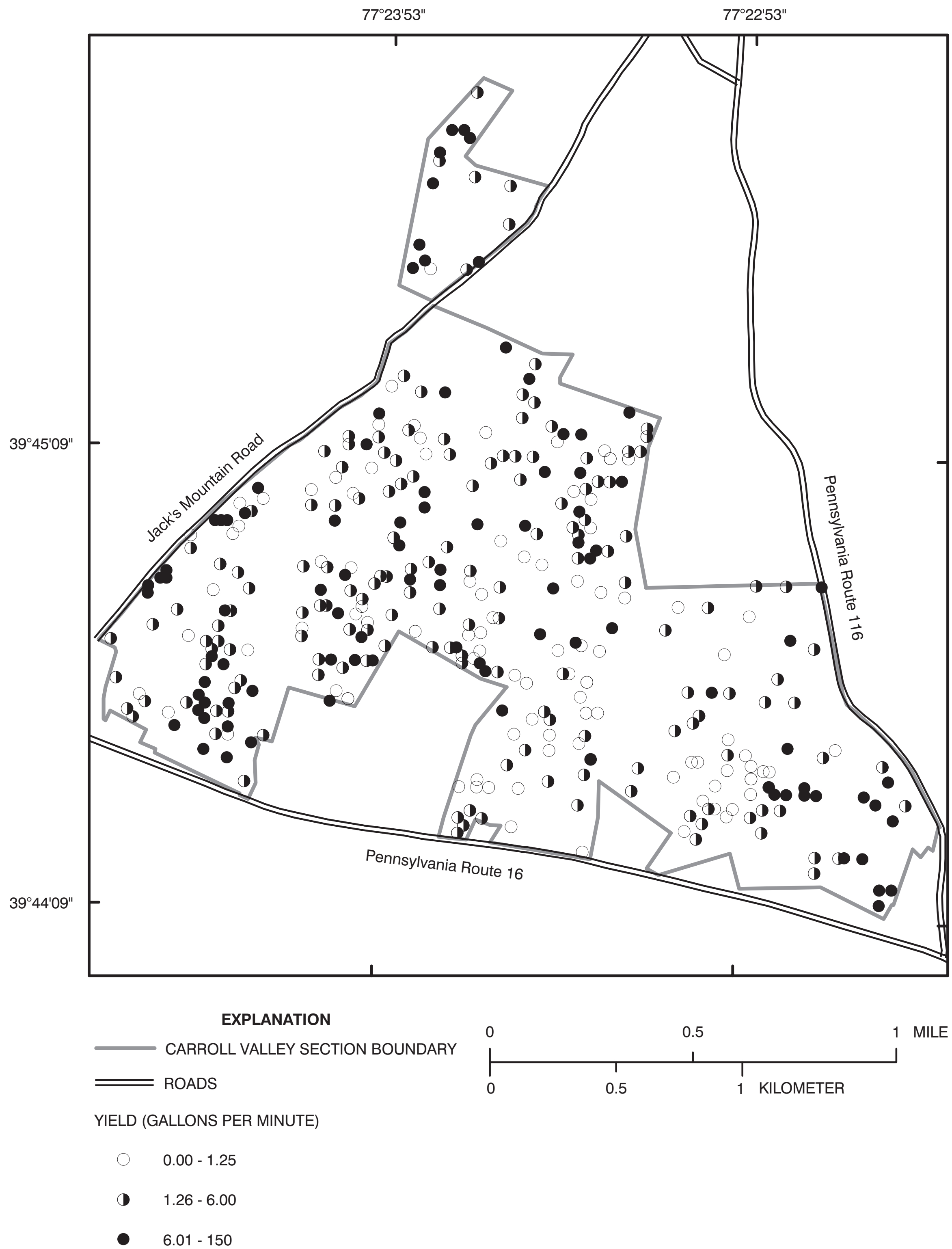


Figure 10. Spatial distribution of driller reported yields in gallons per minute, Borough of Carroll Valley, Adams County, Pennsylvania.

method, however, has been used successfully in the Borough (Randy Alexander, Alexander Well Drilling, oral commun., 2001).

Specific Capacity

Specific capacity is a better measure of the productivity of a geologic formation than yield. Specific capacity is calculated by dividing the yield by the drawdown or the pumping water level (fig. 4). Specific capacity for a well pumped at a constant yield generally decreases with time. Also, specific capacity generally decreases as the discharge increases in the same well.

Specific capacities in the bedrock aquifers of the study area are low. The specific capacities presented in the following table indicate that borehole storage plays an important part in the yield of most wells. Wells that have specific capacities that are 0.04 (gal / min) / ft or less obtain most of the yield from borehole storage and hence are considered incapable of meeting most homeowner or other water-use demands (Low and others, 2002). One way around this restriction, however, is to increase the depth of the well and to locate the pump near the bottom of the borehole. This technique generally provides the well owner with sufficient storage capacity to meet most of their domestic requirements. (A 6-in. diameter borehole will contain 1.47 gal / ft.) As shown below, more than half of the wells drilled into the metabasalt, metarhyolite, and greenstone schist have specific capacities that are less than 0.04 (gal / min) / ft.

Specific capacities of drilled wells by geologic formation

[Specific capacity, in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile; <, less than]

Geologic formation	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Weverton Formation	2	—	—	0.01	—	—	<0.01	0.02
Loudoun Formation	7	—	0.04	.05	0.43	—	<.01	.86
metabasalt	207	<0.01	<.01	.01	.06	0.25	<.01	7.5
metarhyolite	22	<.01	<.01	.02	.04	.25	<.01	.67
greenstone schist	41	<.01	<.01	.01	.05	.12	<.01	.40

Topographic setting also can affect specific capacity. As shown in the following table, wells drilled in the metabasalt and in upland draws generally have greater specific capacities than wells drilled on slopes or hilltops. For the greenstone schist, however, specific capacities tend to be greater on hilltops. The median specific capacity for wells drilled in the greenstone schist and on hilltops (6 wells), slopes (30 wells), and upland draws (5 wells) are 0.07, 0.01, and 0.01 (gal / min) / ft, respectively.

Specific capacities by topographic setting for wells drilled in the metabasalt

[Specific capacity, in gallons per minute per foot of drawdown; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile; <, less than]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	66	<0.01	<0.01	0.02	0.06	0.30	<0.01	0.27
Slope	120	<.01	<.01	.01	.04	.14	<.01	7.5
Upland draw	19	<.01	<.01	.04	.28	.60	<.01	.63
Valley	2	—	—	.04	—	—	<.01	.07

The location of wells with relatively greater specific capacities does not appear to follow a recognizable pattern (fig. 11). In general, wells with greater reported yields have greater specific capacities.

Because of the close relation between yield and specific capacity, aquifer-development techniques that enhance well yield also will increase specific capacity. Secondary development may be a better or cheaper alternative to drilling a new well.

Ground-Water Flow and Recharge

Precipitation is the primary source of groundwater recharge. Much of the precipitation, however, returns to the atmosphere through evapotranspiration or reaches streams as surface runoff or base flow (fig. 12). Evapotranspiration is greatest in late spring, summer, and early fall when plants are actively growing. Surface runoff, however, is greatest in late winter or early spring when the ground is frozen and lowest in late summer and early fall. The remaining precipitation infiltrates into the regolith and the underlying bedrock, flowing from areas of high relief such as Jack's Mountain (high hydraulic head) to areas of low relief such as valleys (low hydraulic head), through joints, cleavage planes, faults, fractures, and other secondary openings. Onlot septic systems also may contribute to ground-water flow and recharge because consumptive use of ground water by homeowners is about 14 percent (U.S. Geological Survey, 1999b).

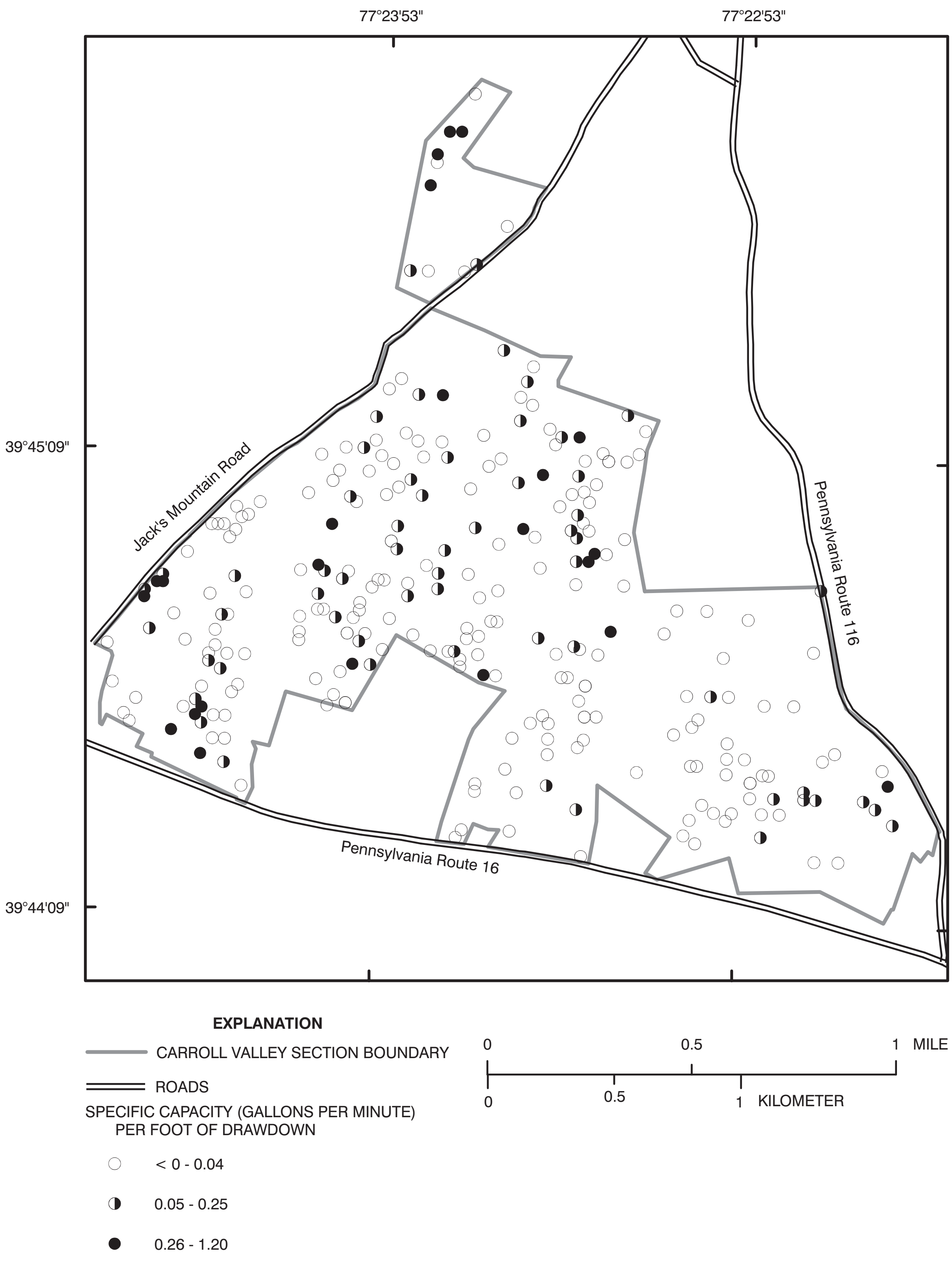


Figure 11. Spatial distribution of specific capacities in gallons per minute per foot of drawdown, Borough of Carroll Valley, Adams County, Pennsylvania.

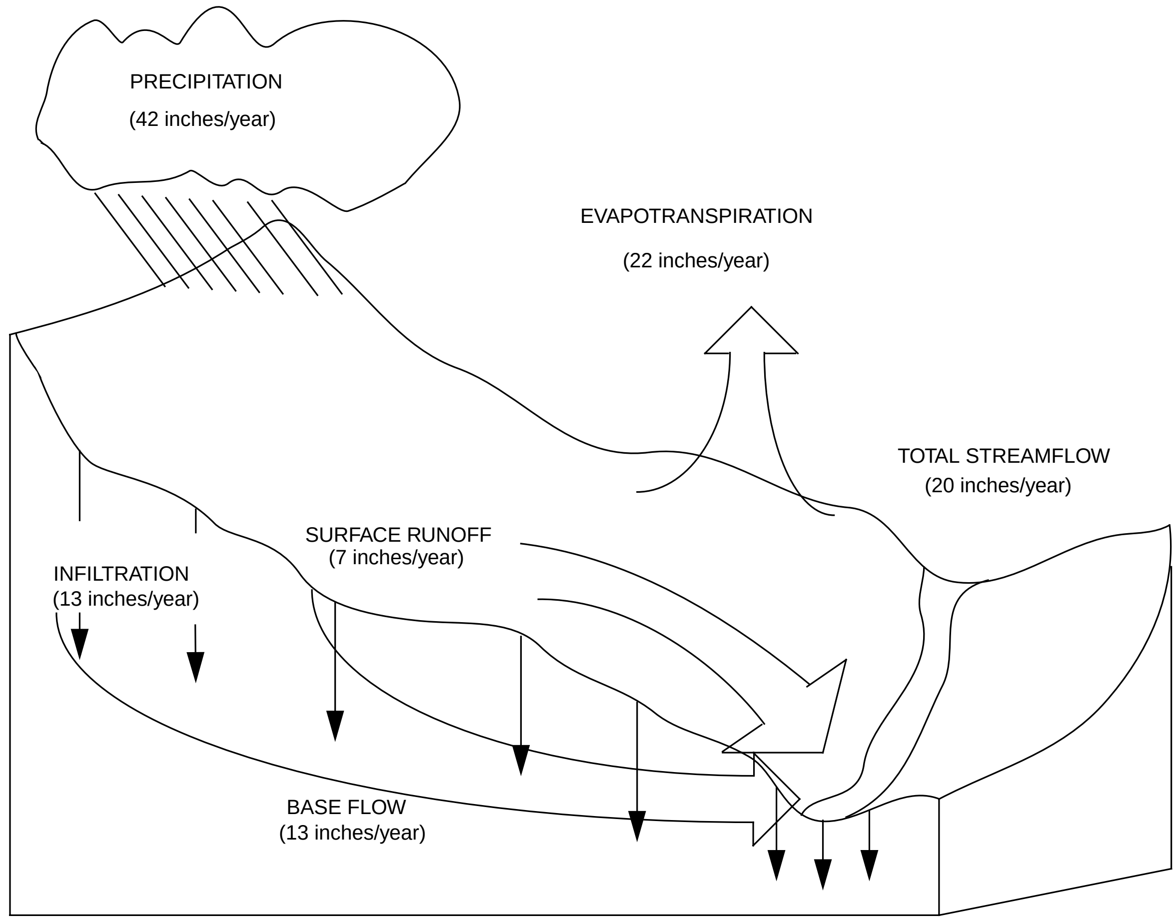


Figure 12. Annual hydrologic cycle for Pennsylvania (modified from Fleeger, 1999, p. 7).

Ground-water flow generally results in a water table that is a subdued replica of the land surface (fig. 3). Water levels are influenced strongly by the amount and duration of precipitation and topographic setting. Where the water table intercepts the land surface, springs can occur. In the Borough, springs are present in Section W where they parallel a north-south trending fault (fig. 2). Two wells in Section H apparently intercept fractures with high hydraulic head because they flow either year round (AD-793) or in the spring (AD-898).

The ground-water system can be considered to consist of two zones—unsaturated and saturated (Davis and DeWiest, 1966). The unsaturated zone is comprised of soil water, intermediate vadose water, and capillary water (fig. 13). Soil water is most important to agriculture because it provides the water for plant growth. Water is lost from this zone by evapotranspiration and percolation when oversaturation occurs. The vadose water and capillary water generally are found in the regolith and can not be used for human consumption but play an important part as a source of recharge to the underlying saturated zone and bedrock aquifers. In the Borough, the unsaturated zone is best represented by regolith that is composed of granular to clayey soil, saprolite, disaggregated bedrock, and colluvium. Regolith can act as a storage medium for water or it can transmit water vertically and horizontally to the underlying bedrock (Driscoll, 1986, p. 59). Thick regolith facilitates infiltration of precipitation and storage and release of water to wells completed in the underlying fractured bedrock. Regolith also can play an important part in maintaining base flow to streams.

The saturated zone contains the shallow ground-water system and the deep ground-water system (fig. 3). The top of the saturated zone is the water table. In the saturated zone, water completely fills the voids or secondary openings. (The saturated zone also may move upward into the regolith, especially during

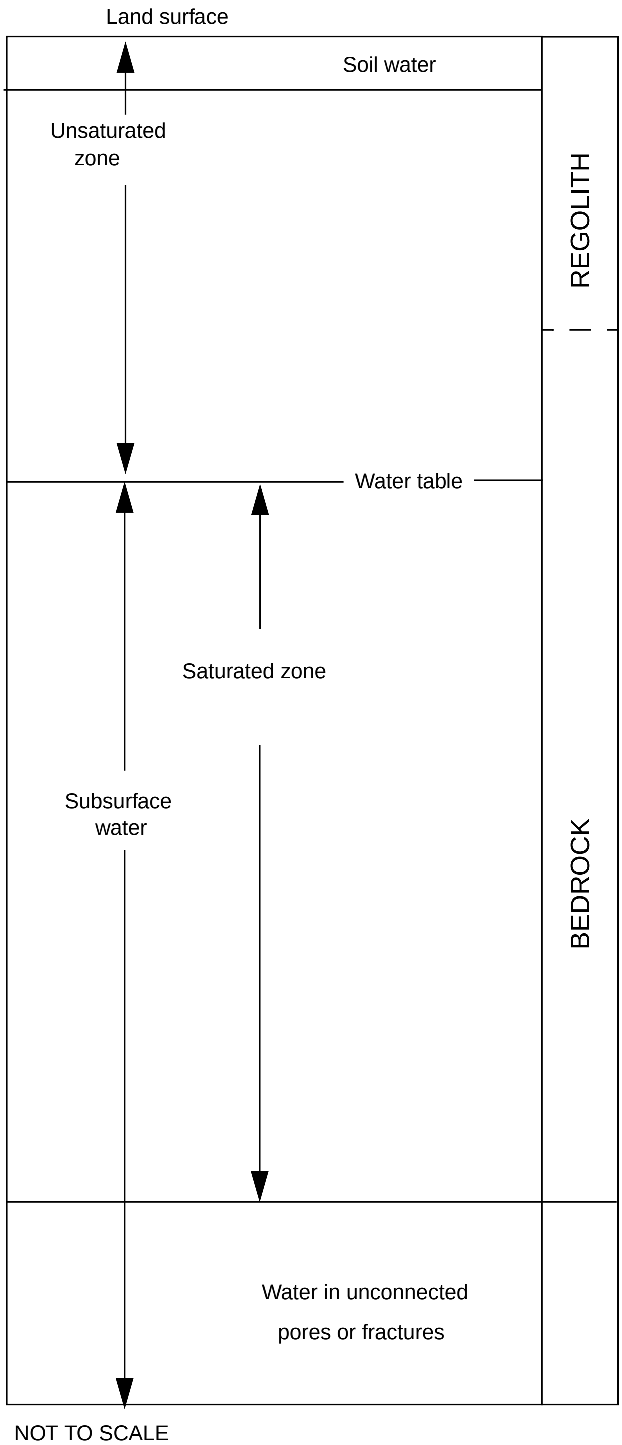


Figure 13. Classification of subsurface water (modified from Driscoll, 1986, p. 60).

extended wet periods.) The water pressure in the saturated zone is high enough to allow ground water to enter a well as the water level in the well is lowered by pumping. The saturated zone gradually grades into areas or regions where ground-water flow is slow and is essentially not available for use (figs. 13 and 14). Water in these secondary openings may not flow toward a well because individual pores are not connected.

The USGS logged three wells, AD-774, AD-808, and AD-836, with a heatpulse flowmeter to evaluate ground-water flow patterns and to determine the depth of the deep ground-water system (appendix B). Ideally, wells on hilltops will show downward flow (ground-water recharge), wells on slopes will show either downward or upward flow, and wells in valleys will show upward flow (ground-water discharge). Well AD-774, which is on a slope, shows upward and lateral flow under nonpumping conditions (table B2). Well AD-808, which is on a hilltop, shows only lateral flow under nonpumping conditions (table B3). Well AD-836, which is also on a hilltop, exhibited no vertical borehole flow under nonpumping conditions (table B4). The three borehole geophysical logs suggest that (1) very little hydraulic head difference exists between water-producing zones, (2) the water-producing zones are not well connected, or (3) both conditions may occur.

The borehole geophysical logs of wells AD-774 (fig. B1; fig. 15), AD-808 (fig. B2), and AD-836 (fig. B3; fig. 15) indicate also that, under nonpumping conditions, most water-producing zones are shallow. The deepest water-producing zone under nonpumping conditions was in well AD-774 at a depth of 254 ft bls. Well AD-836 was the only well of the three to be pumped. Under nonpumping conditions, no vertical borehole flow was identified. Under pumping conditions, vertical borehole flow was measured to a depth of 190 ft with possible vertical borehole flow as deep as 470 ft bls. The deepest reported water-producing zone in the study area is in well AD-807 at a depth of 640 ft bls. The U.S. Government drilled a well (AD-347) in the Catoctin Formation about a mile west of the Borough to a depth of over 9,000 ft. Water in this well flows upward from a depth of at least 600 ft bls. When this information is combined with the depth of driller reported water-producing zones from figures 6 to 9, it suggests the saturated zone exceeds a thickness of 700 ft, but a more practical limit may be a thickness of 400 to 500 ft bls. Additional information regarding borehole geophysical logging is presented in appendix B.

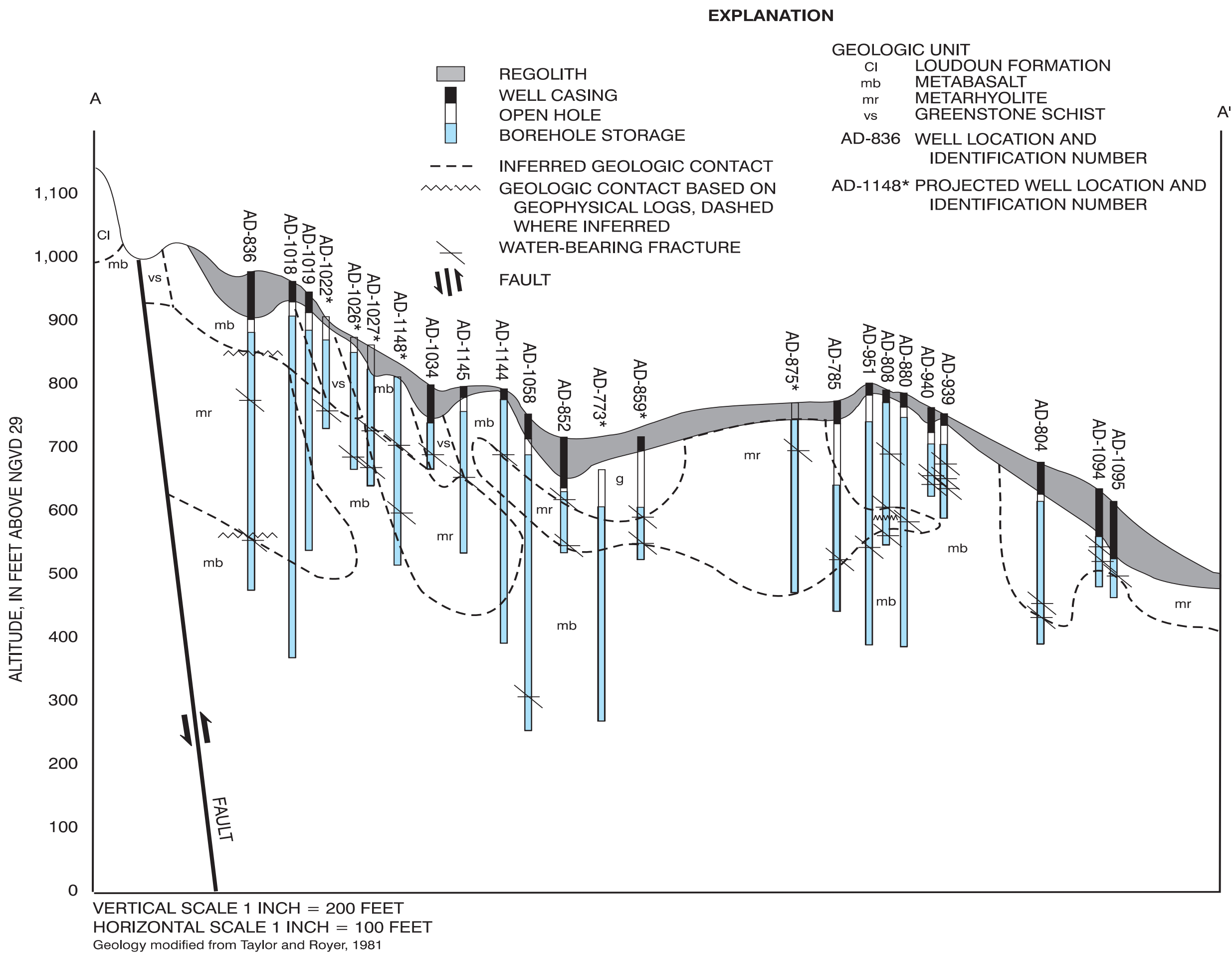


Figure 14. Hydrogeologic cross-section from Jack's Mountain east to Pennsylvania Route 116, Borough of Carroll Valley, Adams County, Pennsylvania.

Water Levels

Water levels fluctuate in response to recharge from precipitation, pumping of wells, seasons, and evapotranspiration. Water levels in wells completed in the fractured bedrock quickly respond to precipitation events (figs. 16-18). This response is primarily the result of the interconnection and low-storage capacity between shallow, high-angle fractures and the overlying, more permeable regolith. Other factors that can induce rapid changes in water levels include (1) air entrapment during recharge, (2) nearby pumping, and (3) atmospheric pressure effects (Freeze and Cherry, 1979, table 6.2).

Water levels typically vary by season and generally rise during the late fall, winter, and early spring when evapotranspiration is at a minimum and recharge is at a maximum. Rising water levels, typical of winter months, can be seen in the records for wells AD-831, AD-832, and AD-846, which cover a period from January 17, 2001, to February 10, 2001 (fig. 16). As seen in the continuous water levels for wells AD-837 and AD-839, which cover a period from February 9, 2001, to March 15, 2001, water levels also may remain fairly steady (AD-839) or even decline (AD-837). However, recharge events of 0.5 in. or greater can result in a considerable rise in water levels (figs. 16 and 17). Snowmelt also can recharge the underlying rocks. The Borough received 4 in. of snow on January 6 and 2.5 in. of snow on January 7, 2001. Daily high temperatures for the period of January 6 to January 17 ranged from a low of 29°F on January 10 to 56°F on January 13. The recharge event related to this snowmelt begins to appear in wells AD-831, AD-832, and AD-846 on January 19 (fig. 16).

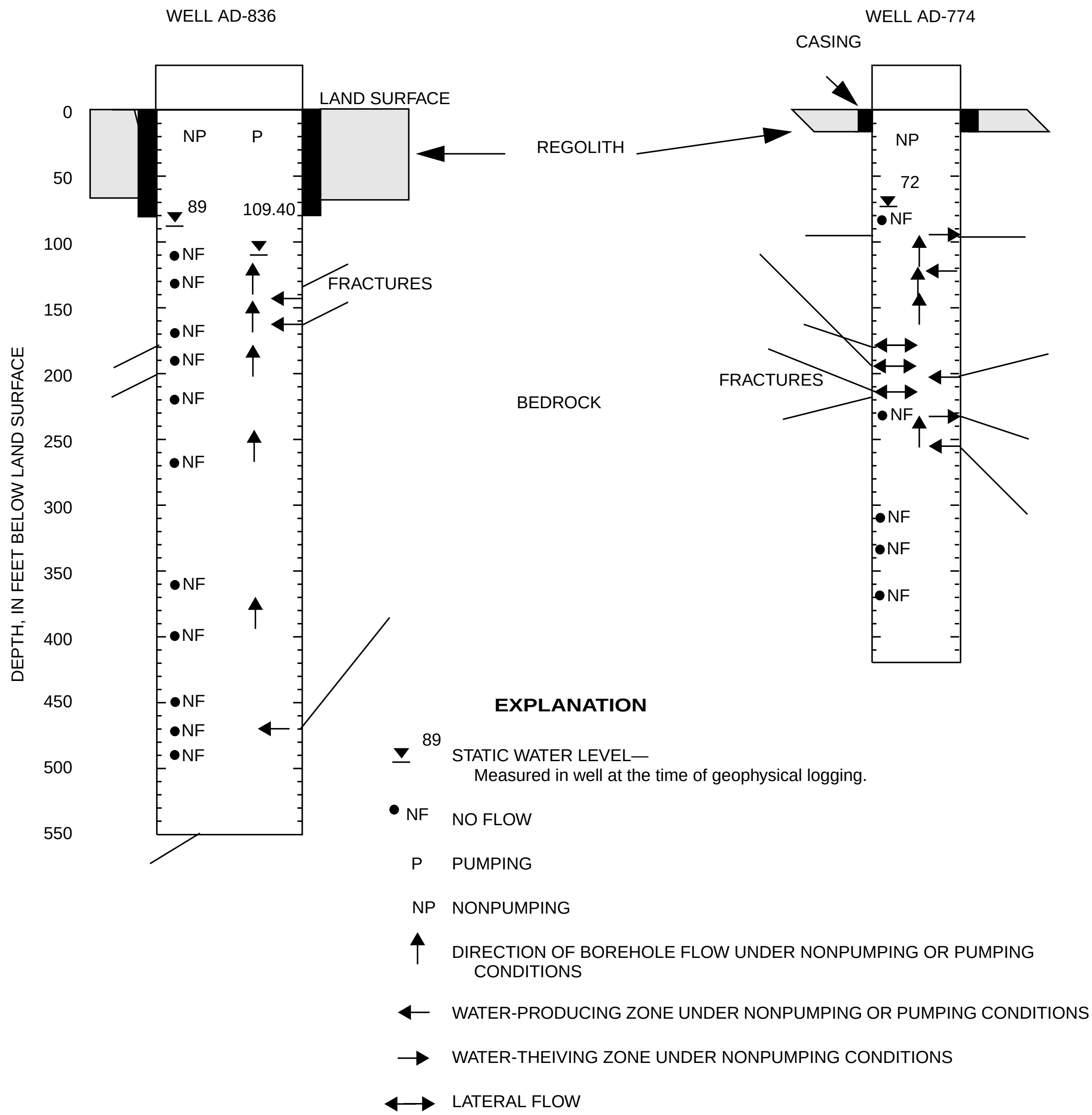


Figure 15. Well-bore flow in wells AD-836 and AD-774 under nonpumping and pumping conditions, Borough of Carroll Valley, Adams County, Pennsylvania.

The typical summer decline in water levels is evident in the continuous water level for well AD-788, which covers a period from May 31, 2001, to August 15, 2001 (fig. 18). Also shown in this well, recharge events tend to flatten, but not reverse, the overall downward trend of the water level.

Wells AD-831 and AD-832 also show the effects of pumping from neighboring wells. The water levels in well AD-831 exhibit many peaks and troughs that correspond to different periods of demand from one or more neighboring wells during a 24-hour period of time. The water level in well AD-832 exhibits only slight and brief declines that occur about 4 days apart. This suggests that well AD-832 is affected by at least one well that is not in the immediate vicinity.

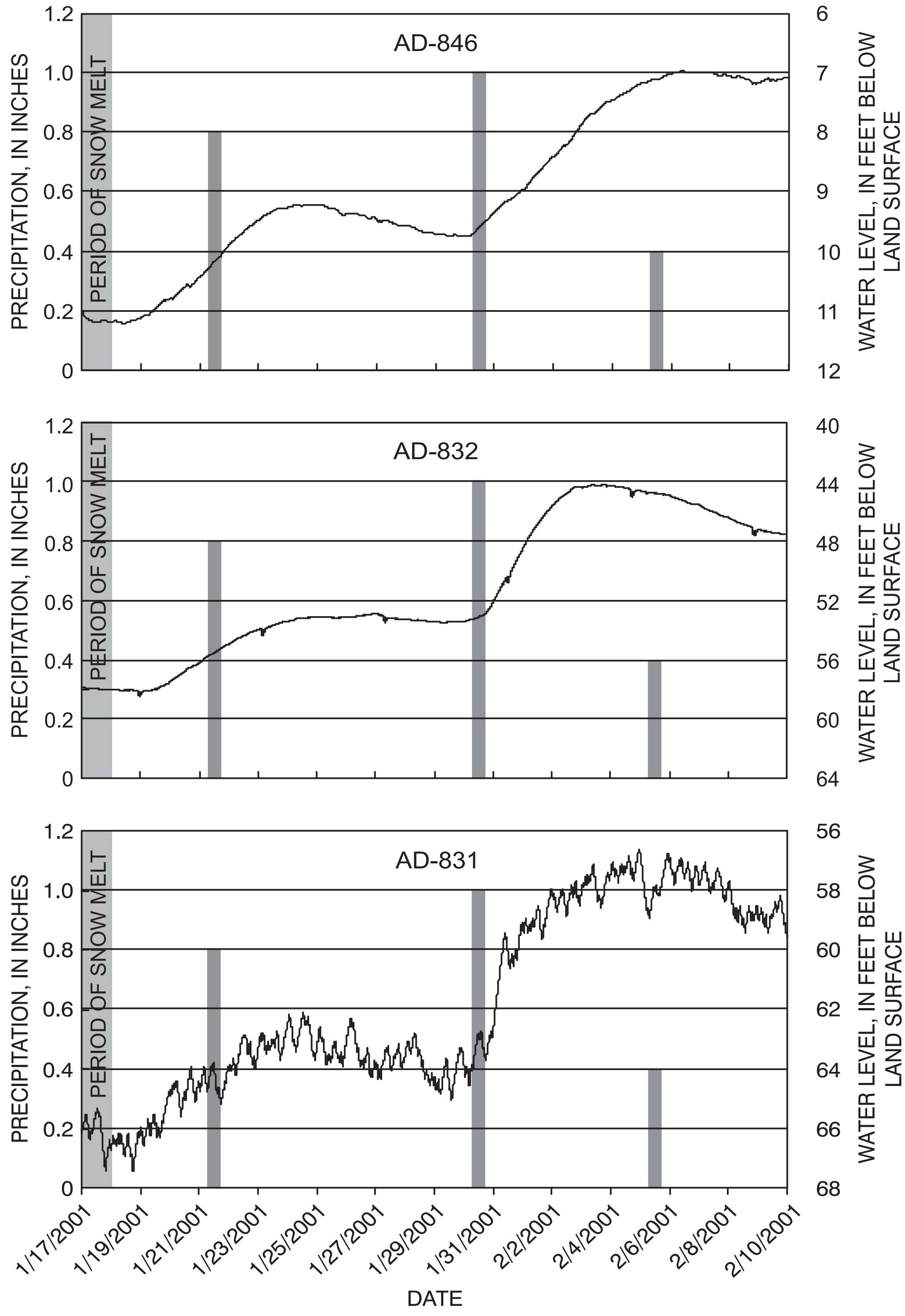


Figure 16. Precipitation and water levels in wells AD-831, AD-832, and AD-846. (Precipitation data collected from sewer plant, Borough of Carroll Valley, Adams County, Pennsylvania.)

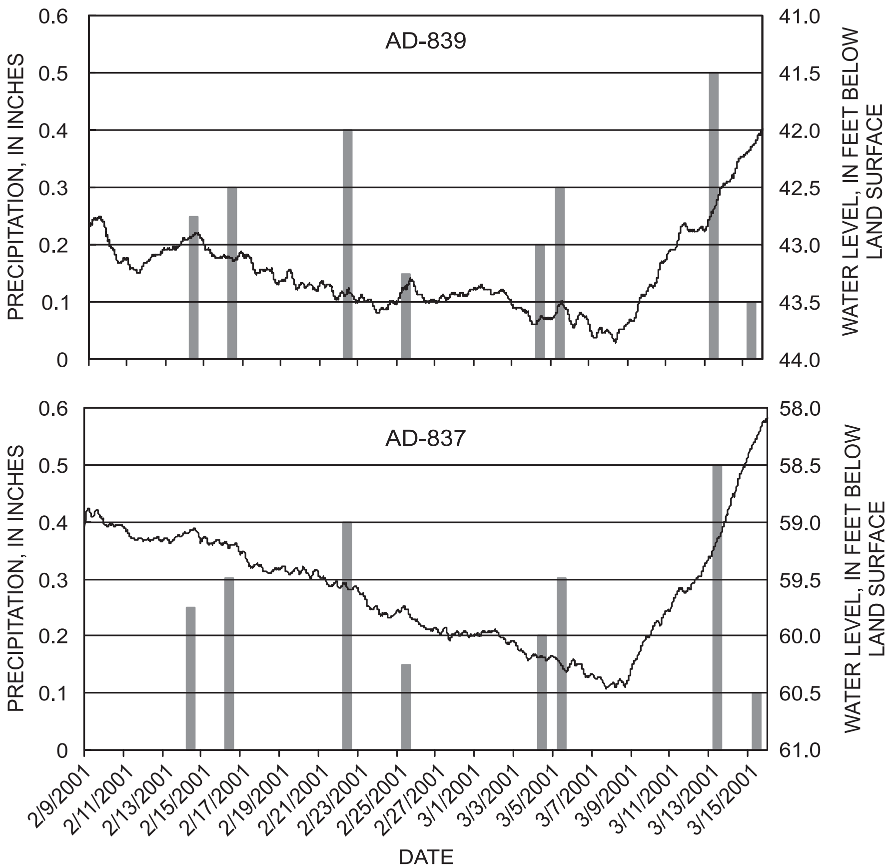


Figure 17. Precipitation and water levels in wells AD-837 and AD-839. (Precipitation data collected from sewer plant, Borough of Carroll Valley, Adams County, Pennsylvania.)

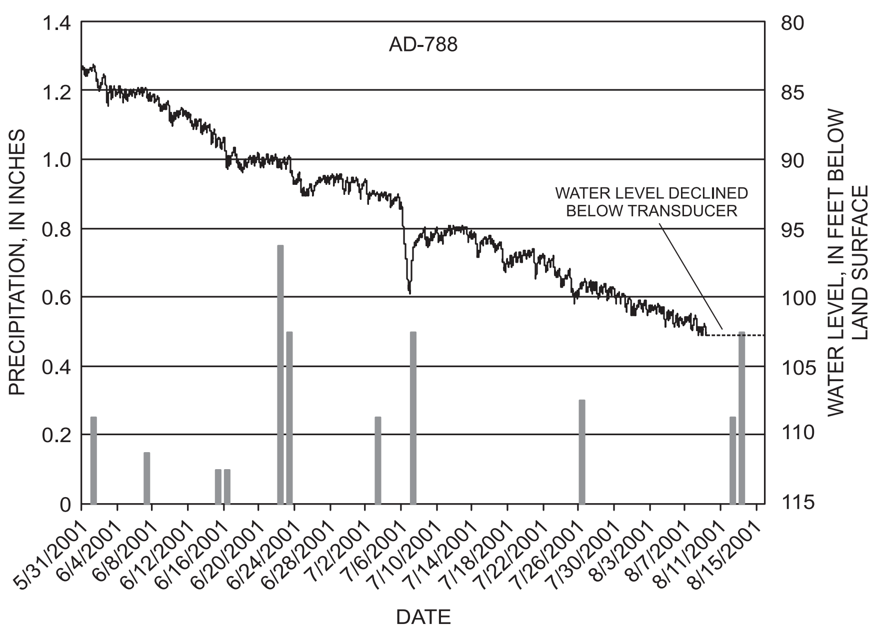


Figure 18. Precipitation and water levels in well AD-788. (Precipitation data collected from sewer plant, Borough of Carroll Valley, Adams County, Pennsylvania.)

The continuous water levels recorded in wells AD-837 and AD-839 may also show the influence of earth tides, which indicates confined ground water (fig. 17). According to Todd (1980, p. 247), “Regular semidiurnal fluctuations of small magnitude... result from earth tides, produced by the attraction exerted on the earth’s crust by the moon and, to a lesser extent, the sun.” Peaks occur at low tide when the earth is compressed. Compression of the bedrock aquifers increases the pressure on confined ground water, which results in rising water levels in wells.

Water levels generally decline during the late spring, summer, and early fall when plant growth is at a maximum and recharge is at a minimum. Because of plant consumption, very little water reaches the shallow or deep ground-water systems and precipitation events, at best, tend to stair-step the seasonal decline rather than reverse the decline (fig. 18). The hydrograph of well AD-788 also shows a large number of peaks and troughs. The water level is affected by one or more wells; the decline on July 6 is the most pronounced.

Water levels also are influenced by topographic setting. As shown in the table below, water levels generally are deeper for wells completed on hilltops than wells completed on slopes, upland draws, or in valleys.

Water level by topographic setting

[Depth, in feet below land surface; —, insufficient data available; P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile; -, indicate water level above land surface]

Topographic setting	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Hilltop	98	20	35.9	50	90	121.1	7	200
Slope	255	20	33.3	50	62	92.4	-2.3	280
Upland draw	33	20	20	40	54.1	80	5	103
Valley	4	—	—	7.1	—	—	5	10.2

Because ground water flows from higher to lower hydraulic head, the general direction of ground-water flow can be estimated from a map of the potentiometric surface. Synoptic water levels were collected on November 14, 2000 (76 wells), and August 15, 2001 (74 wells), to aide in the evaluation of ground-water flow paths and seasonal changes in water levels (figs. 19 and 20). In general, ground-water flow paths and the potentiometric surface during the fall closely resemble that of summer. Depths to water in summer, however, tend to be greater than in the fall; changes range from less than 1 ft (well AD-793) to more than 80 ft (well AD-807). This change in water depth can result in a retreat of water-level contours away from the nearby creeks, toward ridge tops. The changes in water levels between fall and summer, however, do not appear to have been affected by geology or topography. Rather, the fluctuations are distributed randomly. This is probably a result of the low transmissivity of the water-producing fractures and the time between when the pump was last run and when the water level was measured.

Despite the season, ground-water flow directions are dominated by Jack’s Mountain, which directs flow to the southeast along a broad front. Flow along this front is affected by the presence of faults and by changes in topography. Geology may also affect the location of springs because all three inventoried springs are in the greenstone schist.

Seasonal and perennial springs and flowing wells are interspersed in Section H (fig. 2), which is near the base of Jack’s Mountain, with wells that have water levels that are generally 30 to 40 ft below land surface. One well, AD-1063, which was completed at the beginning of August 2001, had a water level 320 ft below land surface at the time of the August 15, 2001, synoptic. Later measurements in well AD-1063 indicated a depth to water of approximately 37 ft.

The north-south trending fault through Sections I and W has a pronounced effect on ground-water flow paths. Springs and wet areas are common on either side of the fault for most of its length. The hydraulic gradient is steeper (water-table contours are more closely spaced) in the vicinity of the fault, which suggests a change (reduction) in the relative permeability of the rocks. Three wells (AD-798, AD-799, and AD-821) in Sections I and W, near the north-south trending fault, consistently have depths to water greater than 100 ft. However, a little further south and also along the fault (near the southeastern corner of Section I) is well AD-797. The water level in well AD-797 is much shallower, typically only 5 to 6 ft below land surface.

The major ridge down the center of the study area represents a ground-water divide that is present throughout the year. The ground-water divide trends in a southeasterly direction. Depths to water in wells on this central ridge tend to be considerably greater than depths to water in wells on the ridge flanks. Also, it is not uncommon, regardless of the season, for wells on the southern part (southeastern part of Section W, Section E, most of Section P) of the central ridge to

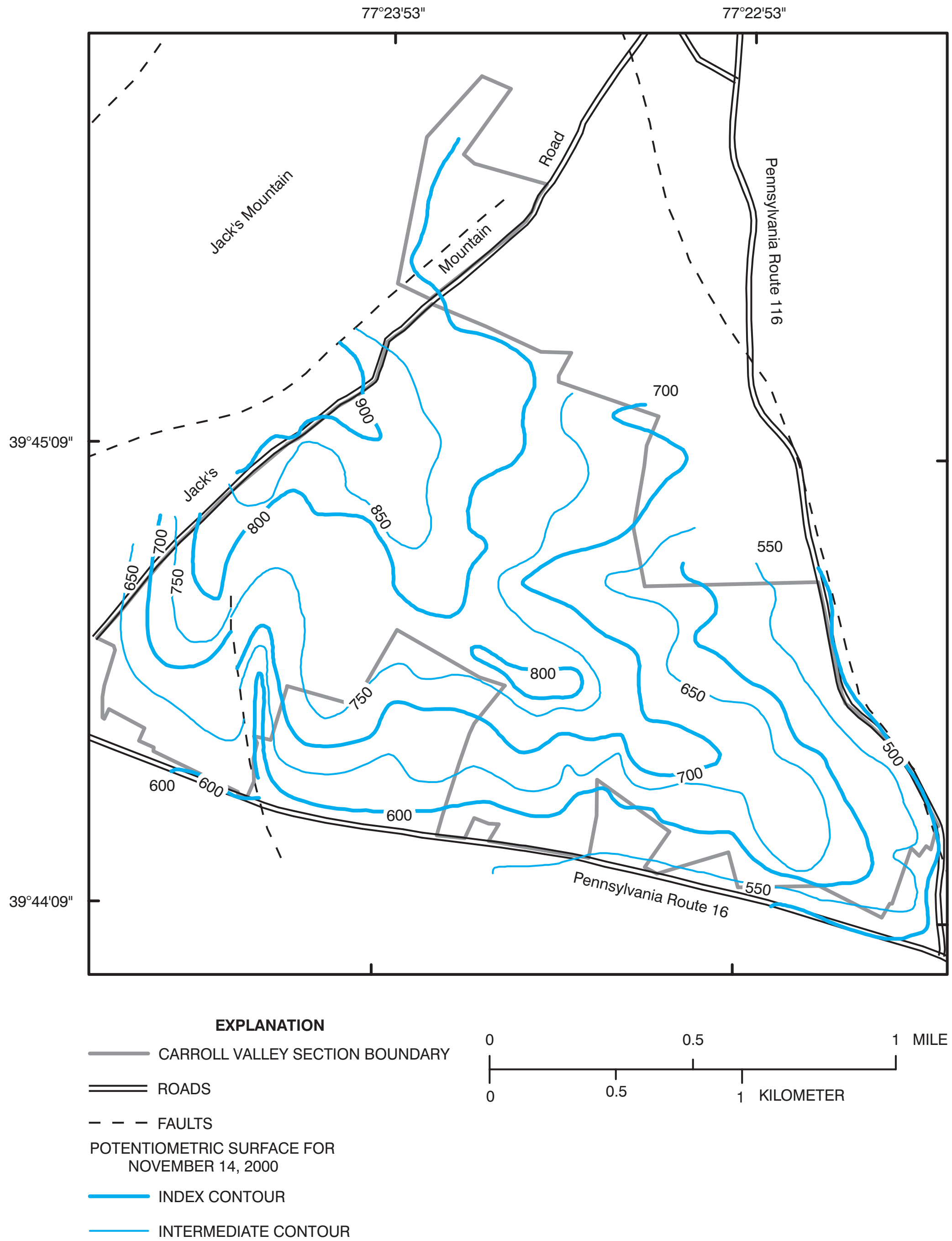


Figure 19. Potentiometric surface for November 14, 2000, Borough of Carroll Valley, Adams County, Pennsylvania.

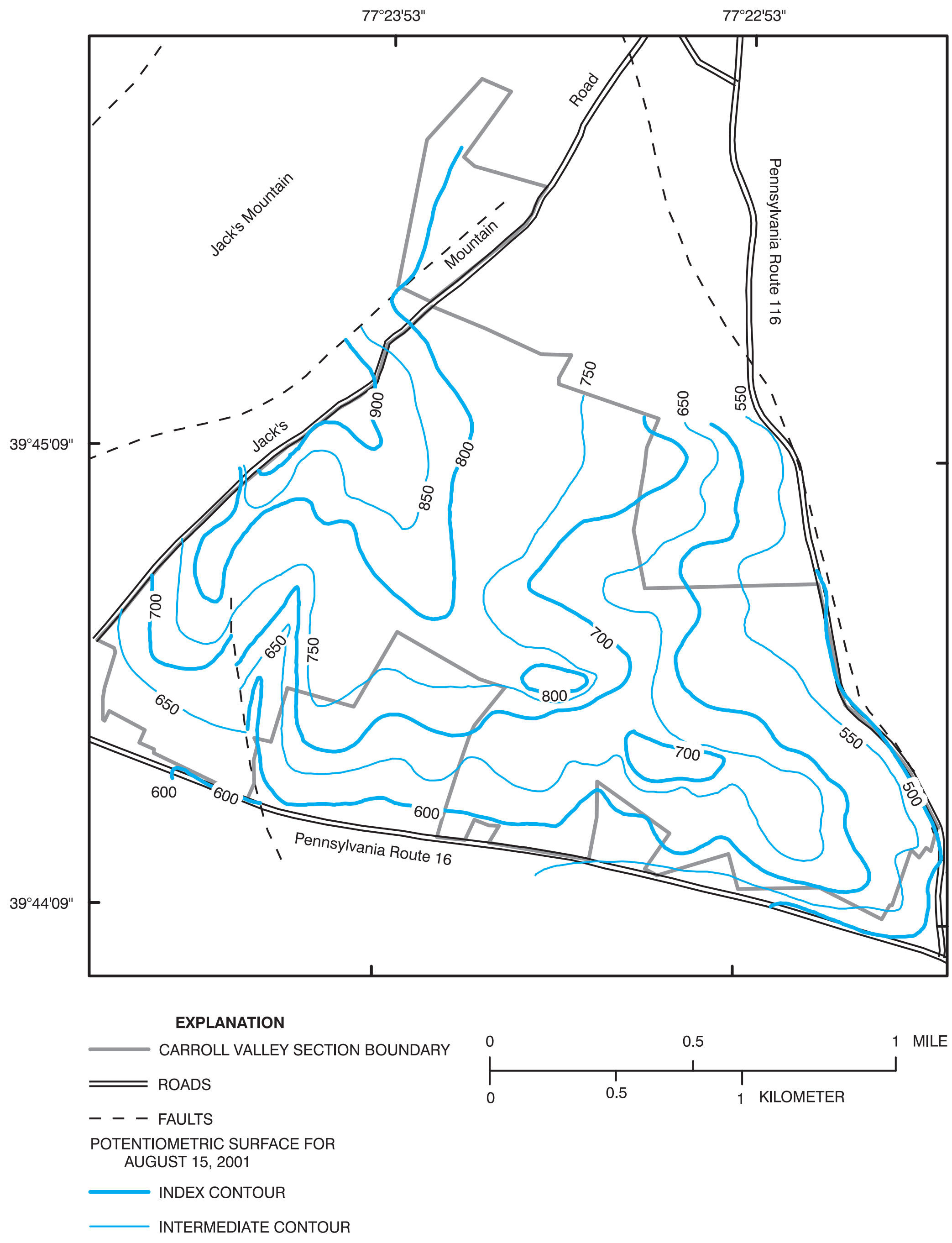


Figure 20. Potentiometric surface for August 15, 2001, Borough of Carroll Valley, Adams County, Pennsylvania.

have depths to water of 100 ft or greater. Ground water on the flanks of the central ridge flow to the south-southwest towards Miney Branch or to the east-north-east towards Toms Creek. Several wells in Sections B and WA (AD-773, AD-833, AD-845, AD-846), near a small tributary to Toms Creek, have relatively shallow water levels. During the synoptic measurements, water levels in these wells ranged from 3.6 to 26.55 ft bls. The small creek is probably a discharge area for ground water.

Bedrock Water Budget

Under predevelopment conditions, the ground-water system is in long-term equilibrium: inflow (recharge from precipitation that infiltrates through the unsaturated zone to the water table and recharge from losing streams, lakes, and wetlands) approximately equals outflow (discharge to streams, lakes, wetlands, and springs or base flow, plus evapotranspiration) or simply:

$$P = SF + ET \,, \qquad (2)$$

where P is precipitation,
SF is stream outflow [(I) infiltration + (RO) surface runoff], and
ET is evapotranspiration.

Humans change this equation by withdrawing (pumping) water, adding impermeable surfaces, changing vegetation, installing onlot septic systems, and introducing irrigation. Because precipitation does not increase, the consumptive use of pumpage must be provided by a decrease in ground-water storage and a decrease in base flow. Equation 1 now becomes:

$$P = SF + ET + Q \,, \qquad (3)$$

where P is precipitation,
SF is stream outflow [(I) infiltration + (RO) surface runoff],
ET is evapotranspiration, and
Q is pumpage.

Pumpage also will reduce water levels. This decline is necessary to induce ground water stored in secondary openings to move toward the pumping wells. Thus, the ground-water system serves as a water reservoir and a water-distribution system (Alley and others, 1999). For most ground-water systems, this change is transient and the system will eventually adjust. Additional stress is introduced by long-term drought by reducing ground-water storage and base flow. Because droughts represent an extreme hydrologic condition, they should be evaluated in any long-term management plan.

Although a detailed bedrock water budget would provide additional geohydrologic information to the Borough, it was beyond the scope of the study to install the stream gages needed for the analysis. However, the efforts of previous workers can provide an approximation of the terms in equation 2 and may prove useful in determining ground-water availability.

Taylor and Royer (1981), who developed a water budget for Adams County, estimated P as averaging about 39 in. per year or 2,930 (gal / d) / acre. They also estimated SF (includes surface runoff plus ground-water recharge) as 15 in. [1,130 (gal / d) / acre] and ET as 24 in. [1,800 (gal / day) / acre]. Taylor and Royer (1981, p. 6) noted also that in drought years as much as 70 to 75 percent of precipitation can be lost to ET.

The 9-year average (1993-2001) precipitation for the Borough is 46.54 in. (Howard Rodriguez, Borough of Carroll Valley, written commun., 2002). This average is very similar to those reported by Sloto (1994) who determined the water budget for a number of surface-water basins in Chester County also underlain by crystalline rocks. The averages from Sloto (1994) are presented in the following table.

Average annual water budget and estimated recharge for selected surface-water basins in Chester County, Pennsylvania (modified from Sloto, 1994)

[All values are shown in inches and in (gallons per day per acre)]

Basin	(P) Precipitation	(SF) Streamflow	(RO) Surface runoff	(ET) Evapotranspiration	(I) Recharge
Darby Creek 1975-88	47.9 (3,590)	23.2 (1,740)	8.7 (653)	24.9 (1,870)	16.3 (1,220)
Crum Creek 1982-88	45.8 (3,440)	18.7 (1,400)	6.7 (503)	27.1 (2,030)	14.0 (1,050)
West Branch Brandywine Creek 1974-88	45.4 (3,410)	21.2 (1,590)	9.3 (698)	24.1 (1,810)	14.0 (1,050)
Three basin average	46.4 (3,480)	21.0 (1,577)	8.2 (618)	25.4 (1,903)	14.8 (1,107)

In 2001, the Borough measured 31.16 in. of precipitation (Howard Rodriguez, Borough of Carroll Valley, written commun., 2002), a decrease in precipitation of 15.38 in. or 33 percent between the 9-year average and the year 2001. Applying a 33 percent reduction from the three-basin average may be a good approximation for drought water budget and estimated recharge to the study area. This information is presented in the following table and equations (note numbers in table are not exact due to rounding).

Drought water budget and estimated recharge for Borough of Carroll Valley, Adams County, Pennsylvania

[All values are shown in inches and in (gallons per day per acre)]

Basin	(P) Precipitation	(SF) Streamflow	(RO) Surface runoff	(ET) Evapotranspiration	(I) Recharge
Borough 2001	31.2 (2,340)	14.1 (1,060)	5.1 (383)	17.1 (1,280)	9.0 (675)

$$P = SF + ET \text{ or} \quad (4)$$

$$31.2 = 14.1 + 17.1 \text{ or} \quad (5)$$

$$P = RO + I + ET \text{ or} \quad (6)$$

$$31.2 = 5.1 + 9.0 + 17.1 \quad (7)$$

This water-budget approximation would suggest that the infiltration for the Borough was about 9 in. or 675 (gal/d)/acre. For the typical 0.5-acre development in the Borough, ground-water recharge would be about 338 gal/d. Mark Sigouin (Pennsylvania Department of Environmental Protection, written commun., 2002) estimates that the average water usage per person is 75 gal/d. For a typical family of four, water usage would then be 300 gal/d or almost the entire infiltration rate of 338 gal/d. Although almost all of the ground-water withdrawn for domestic usage is returned to the regolith via onlot septic systems, the typical domestic well does not have ready access to this recycled water because (1) the well is sealed off from the regolith by grout and steel casing, and (2) the poor interconnection of secondary openings in the bedrock aquifers to the regolith.

Consumptive use for the study area is considered to be that part of water withdrawn that is evaporated or otherwise removed from the immediate water environment (Solley and others, 1998, p. viii). The USGS (1999b) estimates annual domestic consumptive use at about 14 percent with most of it occurring during the summer months or a loss to infiltration of about 42 (gal/d)/acre. In a drought year, this consumptive use would probably be higher owing to increased watering of vegetation.

In summary, detailed work by Sloto (1994) and Taylor and Royer (1981) suggests that infiltration in the Borough, during a drought, may average about 9 in. per year. Assuming that the typical family of four resides on just 0.5 acre, then the infiltration rate (minus 42 gal of consumptive use) is 296 gal/d, or approximately equal to the water usage of 300 gal/d.

Another way to evaluate ground-water availability is to look at well construction and discharge patterns over time. In Pennsylvania, a good well driller will attempt to meet the per capita usage requirement of 75 gal/d by drilling a well that is either deep enough so that a sufficient number of water-producing zones are penetrated or deep enough so that borehole storage is sufficient. If the development of the Borough has had a minimal effect on the bedrock water budget, one would expect only a small increase over time in well depth and little change in reported yield. However, the median depth of a well drilled in the Borough has increased from a low of 209 ft (1980-84) to 400 ft (2000-01) (table 2). This increase in well depth may be attributed to (1) a decline in water levels, (2) a decrease in the productivity of shallow water-producing zones (through a decrease in water levels), (3) warmer temperatures (greater consumptive use), (4) increasing frequency and severity of drought, (5) a transition phase as the ground-water system adjusts to increased pumping and drought, or (6) drillers have become more aware of the low-yielding characteristics of the crystalline-rock aquifers and have compensated by drilling wells deeper.

Sources of Possible Anthropogenic Recharge

The potential for anthropogenic recharge to the crystalline-rock aquifers was evaluated through certain chemical and biological water-quality data collected by the Borough and USGS (appendix C). About every 10 years, the Borough is required by law to collect and analyze water from approximately 10 percent of the existing wells for the presence of nitrate as N and coliform bacteria (total and fecal).

In general, ground water unaffected by contaminant sources contains less than 2 mg/L of nitrate (U.S. Geological Survey, 1999a, p. 34). Of the 35 samples analyzed for nitrate in 2001, 12 (33 percent) had nitrate concentrations greater than 2.0 mg/L as N; one well contained water that exceeded the U.S. Environmental Protection Agency (USEPA) maximum contaminant level (MCL) of 10 mg/L (table 3). Ground water with concentrations of nitrate greater than 2 mg/L may indicate anthropogenic sources such as fertilizer or sewage from septic systems. Leaking or ineffective septic systems, in addition to elevating nitrate concentrations, can cause elevated concentrations of total coliforms, fecal coliforms, and chloride in ground water.

Table 2. *Change, over time, in well depth, yield, and specific capacity, Borough of Carroll Valley, Adams County, Pennsylvania*

[—, not available; yield, in gallons per minute; specific capacity, in gallons per minute per foot of drawdown; ft, feet]

Wells with reported yields					Wells with specific capacities			
Year well drilled	Well depth (median)	Number of wells	Yield (median)	Gallons per 100-ft well depth	Well depth (median)	Number of wells	Specific capacity (median)	Specific capacity per 100-ft well depth
1965-79	311	10	3	0.96	—	—	—	—
1980-84	209	5	3	1.44	209	5	0.12	0.057
1985-89	250	50	6	2.4	250	46	.035	.014
1990-94	305	90	3	.98	320	69	.01	.0033
1995-99	340	149	2.5	.74	360	122	.01	.0028
2000-01	400	48	5	1.25	500	36	.01	.002

Table 3. *Results of analyses for nitrate, coliform, chloride, and bromide in ground water of selected wells, Borough of Carroll Valley, Adams County, Pennsylvania*

[mg/L, milligrams per liter; mL, milliliter; <, less than; —, not analyzed; E, estimated]

U.S. Geological Survey well number	Nitrate 1990 (mg/L)	Nitrate 2001 (mg/L)	Total coliform 1990 (colonies per 100 mL)	Total coliform 2001 (colonies per 100 mL)	Fecal coliform 2001 (colonies per 100 mL)	Chloride 2001 (mg/L)	Bromide 2001 (mg/L)
AD-779	5.4	—	0	—	—	—	—
AD-780	1.7	—	0	—	—	—	—
AD-781	6.6	4.67	4	6	0	13.3	<0.030
AD-783	7.1	—	0	—	—	—	—
AD-790	—	2.07	—	15	0	20.6	.044
AD-800	2.9	1.32	0	0	0	8.6	—
AD-826	7.2	—	0	—	—	—	—
AD-829	—	3.19	—	0	0	4.6	—
AD-830	—	1.05	—	0	0	3.3	<.030
AD-844	—	1.42	—	0	0	5.3	—
AD-845	—	1.62	—	0	0	6.2	—
AD-852	1.7	—	0	—	—	—	—
AD-869	—	5.58	—	135	3	35.9	<.030
AD-873	—	1.32	—	0	0	10.6	E .016
AD-877	—	<1.00	—	0	0	5.3	—
AD-883	<1.00	—	6	—	—	—	—
AD-892	—	4.75	—	0	0	21.0	E .026
AD-900	—	<1.00	—	0	0	1.5	.015
AD-902	—	<1.00	—	0	0	1.3	.010
AD-911	—	<1.00	—	0	0	8.8	—
AD-912	—	<1.00	—	6	0	5.9	—
AD-914	—	1.01	—	0	0	3.7	—
AD-922	—	5.59	—	0	0	8.6	<.030
AD-931	—	1.02	—	0	0	3.8	E .024
AD-941	—	<1.00	—	0	0	10.3	—
AD-947	—	1.27	—	0	0	5.2	—
AD-950	—	1.96	—	0	0	4.9	—
AD-959	—	1.20	—	0	0	7.0	—
AD-960	—	7.31	—	0	0	6.8	E .025
AD-961	—	19.5	—	6	0	13.3	.046
AD-963	—	1.58	—	0	0	4.5	<.030
AD-969	—	1.68	—	0	0	5.2	—
AD-1013	1.6	2.55	0	0	0	5.3	—
AD-1021	—	4.55	—	22	0	8.5	—
AD-1033	—	1.67	—	0	0	5.6	—
AD-1037	—	2.71	—	0	0	13.2	E .025
AD-1077	1.2	1.22	0	0	0	5.7	<.030
AD-1084	—	<1.00	—	0	0	2.1	.024
AD-1098	—	3.79	—	168	2	8.4	.040
AD-1122	—	<1.00	—	0	0	4.0	—
AD-1138	—	1.02	—	0	0	3.7	—

The presence of total coliform bacteria indicates the possibility of sewage contamination. In the study area, total coliforms were detected in 7 of the 35 samples (20 percent) collected in 2001 (table 3). This percentage is similar to that found by Francy and others (2000), who found a relation between the presence of septic systems on the property and the detection of coliforms in water wells. Bacteria survival times in ground water range from days to years and are dependent on temperature, microbial activity, moisture content, pH, salt species and concentrations, soil properties, bacterium type, organic matter, and hydraulic conditions (Yates and Yates, 1988).

Fecal coliform bacteria are found only in the intestines of warm-blooded animals and humans. The presence of these bacteria indicate that sewage wastes or other fecal material are present in the water. Fecal coliform bacteria were found in water from 2 of the 35 wells sampled in 2001 (table 3). The two wells that contained fecal coliform bacteria also contained the greatest number of total coliform bacteria (table 3).

The presence of chloride (along with excessive nutrients or bacteria) where it does not occur naturally also may indicate anthropogenic sources of recharge. Sources of chloride include septic systems (chloride concentrations typically range from 50 to 100 mg/L are common in septic tank effluent), animal waste, potash fertilizer, and drainage from road-salting chemicals.

Concentrations of chloride in water from 35 wells range from 1.3 to 35.9 mg/L, the median is 5.65 mg/L (table 3). The Wilcoxon rank-sum test indicated a significant correlation between the presence of coliform and the concentration of chloride. The median concentration of chloride in wells that contained coliform (7 wells) was 13.3 mg/L; in wells with no coliform (28 wells), the median concentration of chloride was 5.3 mg/L.

In a typical winter, the Borough may use 44 tons or more of road salt to keep their roads clear of snow and ice. To identify sources of chloride, such as road salt in ground water, weight ratios of chloride and bromide concentrations can be used (Whittemore, 1988; Knuth and others, 1990; Davis and others, 1998; Jagucki and Darner, 2001). Chloride and bromide are useful indicators because they are (1) highly soluble, (2) minimally affected by adsorption once dissolved in water, (3) not altered by oxidation-reduction reactions, and (4) not found in high concentrations in igneous rocks (Hem, 1985). Differences in ratios of chloride to bromide occur because bromide is even more soluble in water than chloride (Davis and others, 1998, p. 339). According to Davis and others (1998, table 3), ground water from granitic and metamorphic rocks generally should have a chloride-to-bromide (Cl:Br) ratio that lies between 90 and 140. If road salt (halite) is reaching the ground water, the water will become enriched in chloride relative to bromide and will thus have a high Cl:Br ratio.

Three binary mixing curves (ground water plus halite, domestic sewage plus halite, and dilute ground water) were prepared (fig. 21), following methods described in Whittemore (1988, p. 340) and Jagucki and Darner (2001, p. 38). The sample from well AD-900 was chosen as the dilute ground water end-member because it had one of the lowest Cl:Br ratios and chloride and bromide concentrations. Water from this well also contains no detectable amounts of nitrate or coliform. The Cl:Br ratio of the ground water plus halite end-member was estimated as the mean of three samples of road salt collected by Knuth and others (1990, table 1). The Cl:Br ratio of the domestic sewage end-member was selected following the method used by Jagucki and Darner (2001, p. 38). Mixing curves were calculated by using the formula presented by Whittemore (1998, p. 340).

Jagucki and Darner (2001, p. 40) report that waters with Cl:Br ratios greater than 400 and plotting near or between ground water plus halite and domestic sewage plus halite lines should be considered to have been affected by anthropogenic activities such as road salting or leakage from septic systems. Other factors, such as nitrate concentrations and the presence of coliform, also should be considered when determining the effect of human activities on ground water. For example, well AD-1098 with a Cl:Br ratio of 211 contains water with a nitrate concentration of 3.79 mg/L and total coliform count of 168, which strongly suggests contamination from sewage.

To further discern anthropogenic sources of ground-water recharge, 6 of the 18 wells selected for analysis of Cl:Br ratios also were chosen to evaluate the presence of wastewater compounds in well water. Zaugg and others (2002) have developed a method for the determination of 67 compounds typically found in domestic and industrial wastewater such as non-ionic surfactants, fungicides, herbicides, insecticides, flame retardants, and combustion products. Other, more recognizable named compounds include caffeine, camphor, and menthol. The method was developed in response to concern over endocrine-disrupting chemi-

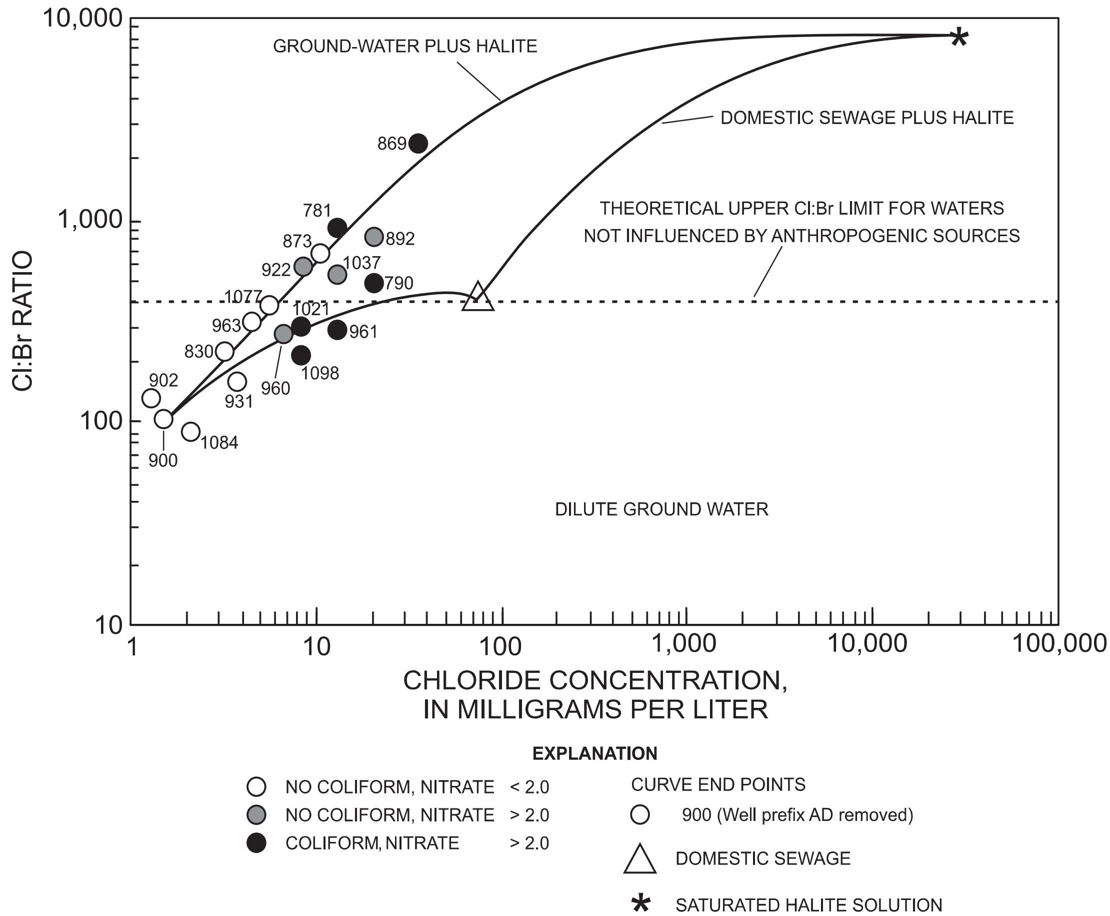


Figure 21. Binary mixing curves for chloride to bromide (Cl:Br) ratios, Borough of Carroll Valley, Adams County, Pennsylvania (modified from Jagucki and Darner, 2001, fig. 14).

cals in wastewater on aquatic organisms. However, this method also may be useful for evaluating the effect of sanitary and storm-sewer overflow on water quality.

The results of the analyses of the 67 wastewater compounds are listed in table D1. The endocrine-disrupting potential and possible compound uses or sources are listed in table D2. Although all six wells contained water with detectable concentrations of wastewater compounds, the concentrations for most of the compounds were below the minimum reporting levels of 1 or 0.5 µg/L (equivalent to parts per billion or ppb). In addition, some of the wastewater compounds detected may be the result of the sampled water being in contact with plastic pipe during the transport of the water from the crystalline-rock aquifer to the sample bottle.

Analysis of the water-quality data indicates that infiltration from onlot septic systems and surface runoff from roads may be reaching wells in the Borough. The exact flow paths taken by the recharge water and the recharge volume, however, remain uncertain. For example, the owners of well AD-900, which contains no detectable concentrations of coliform or nitrate and had the lowest concentration of chloride and bromide, have utilized a holding tank for almost 10 years. Yet, the water in well AD-900 contained 0.68 µg/L Phenol (table D1). For another example, consider well AD-869. The water in well AD-869 contained total and fecal coliforms and elevated concentrations of nitrate and chloride (table 3), suggesting contamination from onlot septic systems. Yet, the concentrations of wastewater compounds Bisphenol A and Triphenyl phosphate were the lowest reported. In essence, although anthropogenic recharge may reach wells in the Borough, this impact is reduced through dilution with native ground water, breakdown via biological processes, and sorption to soils.

ESTABLISHMENT OF A DROUGHT-MONITOR WELL

According to Alley and others (1999, p. 20), droughts can be classified into three principal types (1) meteorological (lack of precipitation), (2) agricultural (lack of soil moisture), and (3) hydrologic (reduced streamflow or ground-water levels). A meteorological drought is the cause of agricultural and hydrologic drought, but the severity of any type of drought is strongly dependent on the timing of the water deficiency. For example, a prolonged dry period during the winter months has only a minor effect on agriculture or ground-water levels because plants are dormant and the ground may be frozen. If the hydrologic drought occurs during the summer, soil moisture is consumed quickly through evapotranspiration and an agricultural drought occurs. If the hydrologic drought occurs when ground water typically is recharged (fall through early spring), then ground-water levels decline, shallow wells go dry, and streamflow decreases. The normal (1960-90) monthly precipitation for South Mountain and the precipitation recorded at the Borough are shown on figure 22. The 2001 precipitation deficit began in the winter months and continued for much of the spring (hydrologic drought), summer (agricultural drought), and fall, cumulating in a meteorological drought with a total precipitation deficit of 13.58 in. The impact of the 2001 drought on water levels can be seen in the hydrograph for well AD-808 (fig. 23).

Meteorological and agricultural droughts are not cumulative and can end relatively quickly by a return to sufficient precipitation. Ground-water systems, however, tend to respond much more slowly. Not only is there a time delay for the precipitation to migrate downward from the soil into the underlying aquifer, but the hydrological drought is cumulative. Enough water must be returned to ground-water storage to return ground-water levels and stream base flows back to near pre-drought levels before the hydrological drought is over.

A common response to hydrologic drought is to drill more wells or to drill existing wells deeper. The success of this response depends on the storage capacity of the underlying aquifer and the extent of existing ground-water development. If storage is large and development minimal, droughts may have limited, if any, effect on well owners. In the study area, however, the storage capacity of the bedrock aquifers is extremely low and the interconnection of the water-producing zones with the overlying soil or regolith is limited. With additional population growth and the resultant increase in ground-water consumption and impervious surfaces, severity of hydrologic droughts will continue to increase in the study area.

Pennsylvania Drought Monitor Network

In 1931, in response to concerns about ground-water-level declines caused by the drought of 1930, a statewide well network was established in Pennsylvania to monitor water-level fluctuations. Today (2002), in cooperation with the PaDEP, the USGS currently operates one observation well in each of Pennsylvania’s 67 counties. Twenty-two wells are in the Ohio River Basin, 30 wells are in the Susquehanna River Basin, and 15 wells are in the Delaware River Basin.

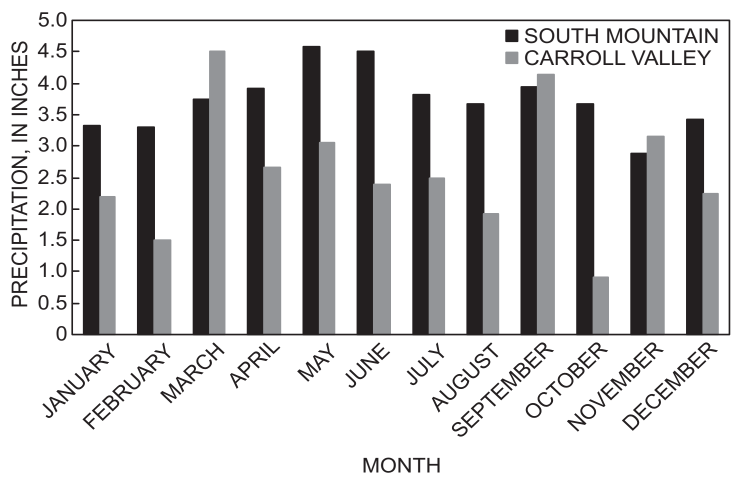


Figure 22. Normal monthly precipitation for South Mountain (1960-90) and monthly precipitation for Borough of Carroll Valley, Adams County, Pennsylvania (2001) (Howard Rodriguez, Borough of Carroll Valley, written commun., 2002).

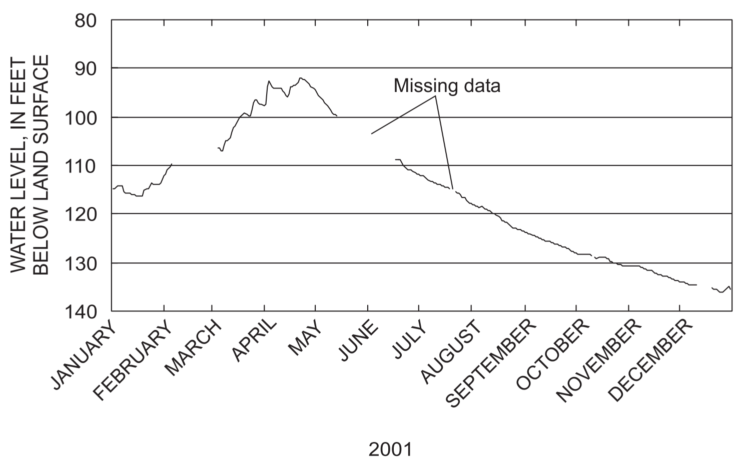


Figure 23. Daily water levels in well AD-808, Borough of Carroll Valley, Adams County, Pennsylvania.

The Commonwealth of Pennsylvania, in cooperation with the Susquehanna River Basin (SRBC) and the Delaware River Basin (DRBC), uses five parameters to assess drought conditions. These include stream flows, precipitation, reservoir storage levels, water levels in the county ground-water observation network, and Palmer Drought Index (a measure of soil moisture). Drought declarations are based on at least three of the five parameters (PaDEP, 2001). Phases of drought preparedness and objectives for water conservation are:

Drought watch - alerts government agencies, water suppliers and users, and the public regarding the onset of conditions indicating the potential for future drought-related problems. A request for voluntary water conservation is made to reduce usage by 5 percent.

Drought warning - prepares governmental agencies for coordinated response to imminent drought conditions, potential water supply shortages, and initiates concerted voluntary conservation measures. The objective is to reduce overall water uses by 10-15 percent.

Drought emergency - concentrated phase of operations by state and local agencies to marshall resources to respond to emergency conditions, avoid depletion of water sources, assure minimum water supplies to protect public health and safety, support essential and high priority water uses, and avoid unnecessary economic dislocations. Mandatory restrictions on nonessential water uses are possible. The objective is to reduce consumptive water use by at least 15 percent.

Up-to-date hydrologic and drought-condition information can be found on the USGS web site at *http://pa.water.usgs.gov.* In addition to the current conditions, this site includes details of the monitoring program, criteria used in drought determination, and in-depth definitions of the various drought levels.

Borough Observation-Well Network and Drought-Monitor Well

As a result of a number of wells going dry in 1998, Borough officials were interested in establishing a drought monitor well within the Borough to aid them in evaluating the local severity of droughts. This well would be completed in the metabasalt or metarhyolite and be protected from outside influences such as property development and pumping from nearby wells. To meet these objectives, the USGS converted 11 wells into long-term (greater than 30 days) observation wells with continuous monitoring of water levels. At least once a month, the water levels in these wells were verified by personnel from the USGS or the Borough utilizing electric tapes. A number of the wells were later removed from the observation well network because of poor construction, pending development of the lot, or utilization of instruments in other wells. By October of 2001, the observation-well network was reduced to six wells. Of the final six wells, well AD-808 was selected to be a drought monitor well for the Borough. This selection was based on several criteria: (1) water level in well reflects seasonal changes, (2) lot cannot be developed (did not pass percolation or “perk” test), (3) surrounding lots are developed, and (4) water level is not affected by pumping from nearby wells.

Well AD-808 is at latitude 39°44'30", longitude 077°22'50", and is owned and operated by the Borough. Well AD-808 has a continuous period of record from October 2, 2000, to present. The well is completed in the metabasalt, has a total depth of 234 ft, and is cased to 20 ft. The well is currently (2002) instrumented with a Stevens Type F analog chart recorder.

Sloto (1994) demonstrated that long-term water-level data from one or more reference or index wells can be related to water levels measured in short-term observation wells by using a regression equation. This method is applicable for areas where water levels represent the natural fluctuation of the water table or potentiometric surface.

Two wells that are part of the Pennsylvania drought monitor network were considered as possible reference wells, AD-146 and CU-2 (fig. 1). The Adams County observation well (AD-146) is at latitude 39°58'46", longitude 077°04'06", at State Game Land No. 249, near York Springs, Pa. The well has a continuous record of water levels from January 1968 to the current year. The well is completed in the Gettysburg Formation of Late Triassic age, has a total depth of 100 ft, and is cased to 17 ft. The Cumberland County observation well (CU-2) is at latitude 40°02'09", longitude 077°18'33", in Michaux State Forest near Pine Grove Furnace, Pa.; the well is owned by the Commonwealth of Pennsylvania and operated by the USGS. Water levels in this well were measured several times per month from June 1951 to March 1955. Water levels were recorded (continuous) beginning in July 1955 and continue to the current year. The well is completed in the metarhyolite, has a total depth of 37 ft, and is cased to 19 ft.

Water levels in well AD-808 (fig. 23) were compared to wells AD-146 and CU-2 for the same time period and a similar pattern of recharge and decline were observed. A regression equation was then developed for each well. In conjunction with the regression equation, a coefficient of determination was calculated to determine how the water-level data were related. A perfectly linear relation would have a coefficient of determination of 1.0000. The coefficient of determination was 0.4522 between well AD-146 and AD-808, but 0.9586 between well CU-2 and AD-808 (fig. 24). On the basis of this analysis of water levels in well CU-2 and well AD-808, the following regression equation was used:

$$Y = 2.2278X + 62.837 , \qquad (8)$$

where Y is the predicted water level in well AD-808 and X is the water level observed in well CU-2. In 2001, the water level in well AD-808 fell below the drought-warning level (90th percentile) in June and stayed below the drought-watch level (75th percentile) from July through September (fig. 25). In November and December, the water level in well AD-808 was again below the drought-warning level.

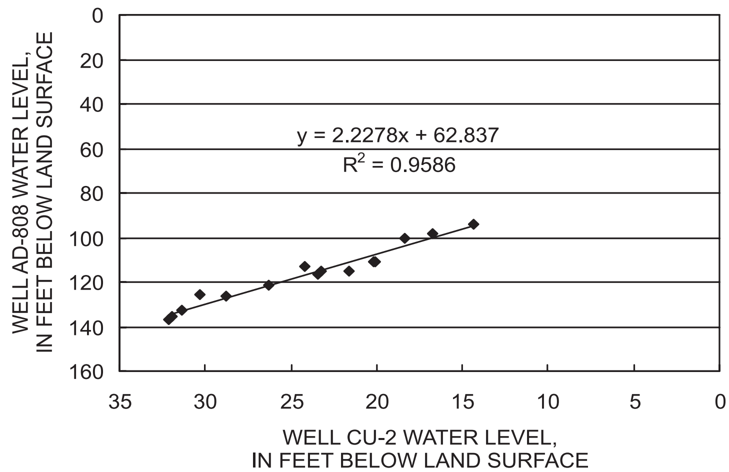


Figure 24. Relation between water levels in Borough of Carroll Valley, Adams County, Pennsylvania, well AD-808 and Cumberland County, Pennsylvania observation well CU-2.

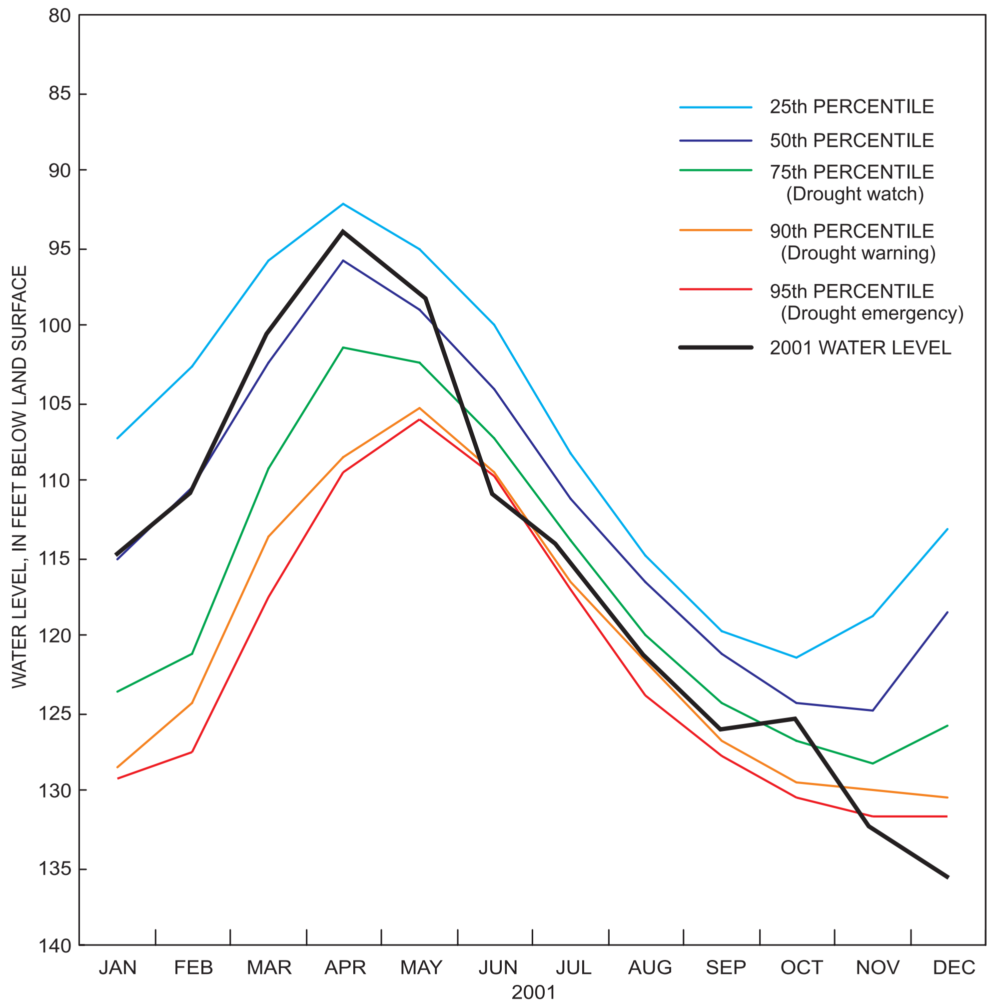


Figure 25. Drought-warning levels for well AD-808, Borough of Carroll Valley, Adams County, Pennsylvania.

SUMMARY AND CONCLUSIONS

Population growth in the Borough of Carroll Valley has increased the demand for ground water. This increased demand, however, has coincided with a series of droughts that have reduced the availability of ground water. Borough officials joined with the USGS to study the geohydrology, ground-water availability, ground-water flow, and the effect of the 2001 drought in the Borough.

The depth and yield of a well is affected directly by the size and distribution of water-producing zones open to the well. Because of the highly resistant, massive, and competent nature of the bedrock, water-producing zones generally are not abundant, productive, or inter-connected. As a result, many wells are deep, subsurface stand or storage pipes. Wells drilled in the metabasalt and greenstone schist generally are deeper than those completed in the metarhyolite; the median well depths in these rocks are 320, 320, and 300 ft, respectively. Wells on hilltops generally are deeper than wells on slopes or in valleys. The deepest well drilled has a reported depth of 780 ft.

Depth to bedrock or regolith thickness is highly variable, ranging from 0 to 115 ft and determining to a large degree how much casing is required. Although regolith commonly absorbs and stores precipitation, there does not appear to be a relation between greater regolith thickness and driller reported yield. Depth to bedrock does vary by geologic formation, however, with more casing required for wells completed in the metarhyolite (median 35 ft) than in the metabasalt (median 28 ft) or in the greenstone schist (median 25 ft).

Driller reports and borehole geophysics indicate that water-producing zones typically are shallow. Fifty percent of the water-producing zones in the metabasalt, metarhyolite, and greenstone schist are penetrated by a depth of 200, 159, and 240 ft, respectively. Ninety percent of the water-producing zones (in all three rock types) are penetrated by a depth of 370 ft. Borehole geophysical data also indicate very little hydraulic head difference between water-producing zones, and water-producing zones generally are not well connected.

The metabasalt, metarhyolite, and greenstone schist are among the lowest yielding rocks in the Commonwealth; median reported yields are 3.0, 4.5, and 3.0 gallons per minute (gal/min), respectively. Well-development techniques can increase yields beyond those obtained through the typical well development method of pumping and surging a well. Specific capacities are low; median specific capacities are 0.01 gallon per minute per foot of drawdown [(gal/min)/ft] for the metabasalt and greenstone schist and 0.02 (gal/min)/ft for the metarhyolite. More than 50 percent of the wells completed in the bedrock aquifers have specific capacities of 0.04 (gal/min)/ft or less. This number indicates that most water comes from borehole storage. Although topographic setting can affect reported yields and specific capacities, this distribution does not appear to have any recognizable pattern in the study area.

Estimates of transmissivity from slug tests range from 2 to 188 feet squared per day (ft^2/d); the median is 26 ft^2/d. Driller drawdown tests indicate that 90 percent of the wells have values of transmissivity and hydraulic conductivity less than 100 ft^2/d and 1 foot per day, respectively. Ground-water flow paths are very complex and strongly affected by topography, geology, sources of recharge, and pumping.

Water levels fluctuate in response to recharge from precipitation, pumping of wells, and evapotranspiration. Water levels in wells completed in the fractured bedrock quickly respond to precipitation events. Although precipitation events and changes in the season can greatly affect water levels, the effects are generally short lived. Despite the season, synoptic water-level measurements indicate that ground-water flow directions are dominated by Jack’s Mountain and that the major ridge down the center of the study area represents a ground-water divide. Ground-water flow generally results in a water table that is a subdued replica of the land surface.

The principal source of ground-water recharge in the Borough is precipitation. Inflow from topographically higher areas that border the Borough also occurs. Approximately half of the 46 in. of precipitation returns to the atmosphere through evapotranspiration, and surface runoff to streams and base flow account for the remainder.

In general, the ground-water system is under stress. Humans effect the ground-water budget by withdrawing water, adding impermeable surfaces, changing vegetation, installing onlot septic systems, and introducing irrigation. The consumptive use of pumpage must be provided by a decrease in ground-water storage and a decrease in base flow. During 2001, the estimated ground-water infiltration rate on a 0.5-acre lot was approximately 9 inches per year or

300 gallons per day (gal/d). A typical family of four residing on just 0.5 acre also uses 300 gal/d. This analysis suggests that during drought years, the ground-water system is severely stressed and that declining water levels, decreased ground-water availability, and reduced base flow will continue for an unknown period of time.

The use of data on selected chemical (nitrate, chloride, bromide), biological (coliform), and wastewater compounds to identify potential sources of anthropogenic recharge showed mixed success. Total coliform bacteria (7 of 35 wells), fecal coliform bacteria (2 of 35), and elevated concentrations (greater than 2 mg/L) of nitrate (12 of 35 wells) were found. There was a significant correlation between the concentration of chloride and wells that contained coliform bacteria. Chloride to bromide ratios from 18 wells ranged from 88 (dilute ground water) to 1,200 [ground water probably effected by anthropogenic source(s)]. The water in six wells was analyzed for 67 wastewater compounds. Although six wastewater compounds were found, concentrations were very low, ranging from 0.02 to 1.2 μg/L. The presence of total and fecal coliform bacteria, nitrate, and Cl:Br ratios indicate that some of the ground-water recharge reaching domestic wells in the study area is affected by anthropogenic sources that may include fertilizer, road salt, or sewage. The flow paths taken by the recharge water and volume of recharge, however, remains uncertain.

Through the use of continuous water-level recorders, borehole geophysical surveys, slug tests, driller logs, and adjacent county observation wells, the USGS was able to identify well AD-808 as a suitable candidate for a drought-monitoring well in the Borough. In 2001, the water level in well AD-808 fell below the drought-warning level (90th percentile) in June and stayed below the drought-watch level (75th percentile) from July through September. In November and December, the water level in well AD-808 was again below the drought-warning level.

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Table 4. *Records of selected wells and springs, Borough of Carroll Valley, Adams County, Pennsylvania*

Latitude and longitude: Location of well determined to the nearest second from topographic maps and to the nearest tenth of a second by a Global Positioning System (GPS). Examples: 394428 represents 39°44'28", 394429.7 represents 39°44”29.7". Horizontal coordinate datum for wells located by GPS is NAD 83, datum for other wells is NAD 27.

Date completed: Date of well construction as reported on driller’s log, in m/d/y, m/y, or y format.

Altitude of land surface: Land surface at well site, in feet above NGVD 29.

Topographic setting: S, slope; H, hilltop; V, valley; W, upland draw.

Hydrogeologic unit: 000MBSL, metabasalt; 000MTRL, metarhyolite; 000GRNS, greenstone schist; 377 WVRN, Weverton Formation; 377 LUDN, Loudoun Formation.

Depth of well: Depth of drilled well, in feet below land surface, as reported on driller’s log.

Casing length: Feet of casing used to complete well, as reported on driller’s log.

Static water level: Depth of water, in feet below land surface, as measured by USGS personnel or reported by driller or owner.

Date water level measured: m/d/y, m/y, or y format.

Driller reported yield: in gallons per minute.

Specific capacity: in gallons per minute per foot of drawdown.

Depth to bedrock: Depth, in feet below land surface, to bedrock as reported on driller’s log.

<, less than; >, greater than; F, flowing well; —, no data.

Table 4. *Records of selected wells and springs, Borough of Carroll Valley, Adams County, Pennsylvania*

USGS well identification number	Location		Driller	Date completed	Altitude of land surface (feet)	Topo-graphic setting	Hydrogeologic unit	Depth of well (feet)
	Latitude	Longitude						
AD-516	394428	0772318	Eichelberger	9 / 20 / 1978	730	S	000MBSL	550
AD-771	394453	0772245	Alexander	6 / 1986	580	S	000MBSL	230
AD-772	394450	0772254	—	2000	630	S	000MBSL	—
AD-773	394452	0772315	Eichelberger	11 / 1998	670	V	000MBSL	400
AD-774	394439	0772239	—	2000	620	S	000MBSL	398
AD-775	394445	0772240	Alexander	2 / 16 / 2000	570	S	000MBSL	240
AD-776	394426	0772231	Alexander	3 / 21 / 2000	670	S	000MTRL	340
AD-777	394446	0772324	—	1988	805	S	000MBSL	80
AD-778	394445	0772318	Alexander	5 / 8 / 2000	780	S	000MBSL	500
AD-779	394444	0772308	Reichart	2000	745	S	000MTRL	—
AD-780	394440	0772319	Alexander	2000	860	S	000MBSL	260
AD-781	394438	0772319	Alexander	10 / 3 / 1995	875	H	000MBSL	500
AD-782	394438	0772320	D.H. Woodward	1975	880	H	000MBSL	—
AD-783	394438	0772320	—	2000	880	H	000MBSL	—
AD-784	394436	0772318	Alexander	1998	850	H	000MTRL	600
AD-785	394433	0772254	Alexander	10 / 19 / 1995	750	S	000MBSL	300
AD-786	394432	0772244	Harley	6 / 26 / 2000	740	W	000MBSL	400
AD-787	394431	0772238	Alexander	8 / 6 / 1991	680	S	000MTRL	340
AD-788	394429.7	0772317.1	Alexander	2000	760	W	000MBSL	380
AD-789	394546	0772346	Woodward	1972	830	S	377WVRN	400
AD-790	394421	0772330	Alexander	8 / 1990	660	S	000MBSL	615
AD-791	394422	0772339	Alexander	2 / 1994	630	S	000GRNS	500
AD-792	394433	0772330	Alexander	11 / 7 / 1998	800	S	000MBSL	700
AD-793	394541	0772340	—	1990	790	S	000MBSL	—
AD-794	394534	0772347	—	2 / 15 / 2000	820	W	000MBSL	225
AD-795	394435	0772427	Reichart	4 / 2 / 1997	690	S	377LUDN	300
AD-796	394433	0772427	Alexander	11 / 1989	680	W	000MBSL	100
AD-797	394431	0772414	Harley	6 / 28 / 2000	650	W	000MBSL	300
AD-798	394438.4	0772413.8	Alexander	10 / 27 / 1999	740	S	000MBSL	400
AD-799	394439	0772413	—	2000	700	H	000MBSL	—
AD-800	394445.3	0772424.8	W. Funt	7 / 1988	820	S	000MBSL	170
AD-801	394451.3	0772420.9	Alexander	6 / 1991	890	H	000MBSL	500
AD-803	394418	0772234	Harley	6 / 27 / 2000	680	S	000MTRL	225
AD-804	394418	0772235	Alexander	2 / 26 / 2000	680	S	000MTRL	280
AD-805	394416	0772239	—	1972	680	S	000MTRL	200
AD-806	394426	0772239	Alexander	10 / 9 / 1995	730	S	000MBSL	260
AD-807	394425	0772258	Alexander	5 / 4 / 2000	780	S	000MBSL	750
AD-808	394429.9	0772249.8	Keyser	10 / 16 / 1969	790	H	000MBSL	234
AD-809	394428	0772250	Alexander	7 / 28 / 1995	780	H	000MBSL	300
AD-814	394458	0772424	—	7 / 2000	830	S	000GRNS	300
AD-815	394500	0772420	Alexander	3 / 28 / 1997	860	S	000GRNS	600
AD-816	394500.3	0772418.2	Alexander	11 / 2 / 1996	860	S	000MBSL	780
AD-817	394500.7	0772419.3	Alexander	6 / 18 / 1997	865	S	000GRNS	600
AD-818	394503.4	0772412.2	Alexander	5 / 3 / 2000	905	H	000MBSL	600
AD-819	394501.1	0772415.1	Alexander	8 / 14 / 2000	895	H	000MBSL	640

Table 4. *Records of selected wells and springs, Borough of Carroll Valley, Adams County, Pennsylvania—Continued*

Casing		Depth(s) to water-producing zone(s) (feet)	Static water level (feet below land surface)	Date water level measured	Driller reported yield (gal/min)	Specific capacity (gal/min)/ft	Depth to bedrock (feet)	USGS well identification number
Length (feet)	Diameter (inches)							
42	6	400; 485	91.95	8/15/2001	3	—	—	AD-516
50	6	—	55.87	8/15/2001	6	—	—	AD-771
—	6	—	64.16	8/15/2001	—	—	—	AD-772
60	6	—	7.14	8/15/2001	1	—	—	AD-773
12	6	50	72.83	8/15/2001	—	—	—	AD-774
60	6	110; 170; 225	32.64	8/15/2001	5	0.04	48	AD-775
60	6	140; 260	96.2	11/6/2000	7	.1	48	AD-776
—	6	—	65.05	8/15/2001	—	—	—	AD-777
40	6	190; 260; 360	102.97	8/15/2001	3	.01	—	AD-778
—	6	—	56.54	8/15/2001	—	—	—	AD-779
—	6	—	49.59	8/15/2001	—	—	—	AD-780
40	6	—	137.05	8/15/2001	.25	<.01	30	AD-781
—	6	—	109.5	8/15/2001	—	—	—	AD-782
—	6	—	135.38	8/15/2001	—	—	—	AD-783
40	6	—	> 151	8/15/2001	.1	<.01	—	AD-784
40	6	220	135.77	8/15/2001	1	<.01	30	AD-785
21	6	345; 365	10.2	8/15/2001	8	—	10	AD-786
40	6	250; 300	87.73	8/15/2001	1.5	.01	30	AD-787
30	6	300; 340	102.97	8/15/2001	15	—	15	AD-788
120	6	185	3	1972	3	<.01	115	AD-789
21	6	—	72.08	8/15/2001	0	<.01	8	AD-790
40	6	460	34.66	8/15/2001	5	—	25	AD-791
20	6	—	79.8	11/14/2000	.25	<.01	—	AD-792
—	6	—	-2.3F	8/15/2001	—	—	—	AD-793
60	6	215	43.04	8/15/2001	12	—	—	AD-794
63	6	84; 140; 220	47.95	8/15/2001	3	—	4	AD-795
42	6	80	54.09	8/15/2001	12	.6	35	AD-796
42	6	230; 260	6.15	8/15/2001	15	—	30	AD-797
40	6	290	105.13	8/15/2001	2.1	—	10	AD-798
—	6	—	102.42	8/15/2001	—	—	—	AD-799
55	6	70	66.56	8/15/2001	5	.04	48	AD-800
20	6	—	84.96	8/15/2001	1	<.01	10	AD-801
53	6	210	52	8/15/2001	20	—	45	AD-803
47	6	220; 240	57.34	8/15/2001	6	.04	35	AD-804
35	6	80	31.31	11/14/2000	3	—	35	AD-805
60	6	160; 225	49.4	8/15/2001	8	.06	50	AD-806
20	6	247; 640	224	8/15/2001	1.25	<.01	3	AD-807
20	6	98; 178; 225	12.31	8/15/2001	2	—	10	AD-808
27	6	—	dry	7/28/1995	0	0	10	AD-809
31	6	—	44.16	8/15/2001	7	—	—	AD-814
21	6	—	92.76	8/15/2001	1.81	.01	10	AD-815
21	6	260	147.91	8/15/2001	.33	<.01	3	AD-816
28	6	—	81.81	8/15/2001	.85	<.01	15	AD-817
41	6	460; 560	16.7	8/15/2001	2	.01	25	AD-818
40	6	210; 350	76.4	8/15/2001	1.3	<.01	20	AD-819

Table 4. *Records of selected wells and springs, Borough of Carroll Valley, Adams County, Pennsylvania—Continued*

USGS well identification number	Location: Latitude	Location: Longitude	Driller	Date completed	Altitude of land surface (feet)	Topo-graphic setting	Hydrogeologic unit	Depth of well (feet)
AD-820	394451	0772415	Alexander	8/12/1995	810	S	000MBSL	220
AD-821	394443	0772418	Alexander	8/2000	800	S	000GRNS	360
AD-822	394455.3	0772402.3	Alexander	8/18/2000	790	W	000GRNS	160
AD-823	394442	0772403	Alexander	6/2000	780	S	000GRNS	500
AD-824	394437.4	0772400.9	Alexander	3/13/2000	820	S	000MBSL	500
AD-825	394448	0772351	Alexander	4/1990	890	H	000GRNS	310
AD-826	394440.4	0772327.3	—	1965	880	H	000MBSL	150
AD-827	394443.2	0772336.2	Alexander	1/1998	880	H	000MBSL	400
AD-828	394441.7	0772329.6	—	1975	880	H	000GRNS	—
AD-829	394444.0	0772335.8	Alexander	12/21/1995	880	H	000MBSL	500
AD-830	394446.4	0772337.4	Alexander	2/1990	870	H	000MBSL	520
AD-831	394453.0	0772347.9	Alexander	3/14/2000	885	H	000MBSL	420
AD-832	394454	0772348	Alexander	12/19/1998	900	H	000MBSL	300
AD-833	394453.5	0772337.0	—	7/2000	820	S	000MBSL	160
AD-834	394518.4	0772351.3	Alexander	3/11/1997	960	H	000MBSL	400
AD-835	394513.2	0772347.4	—	2000	950	S	000MBSL	—
AD-836	394513.9	0772353.8	—	6/6/1999	980	H	000MBSL	500
AD-837	394511	0772354	Alexander	1/14/2000	970	H	000MBSL	400
AD-838	394506.9	0772400.9	Alexander	4/28/2000	900	S	000MBSL	500
AD-839	394504.3	0772357.8	Alexander	4/17/1997	900	S	000MBSL	240
AD-840	394508	0772310	—	1984	760	H	000MBSL	180
AD-841	394506	0772313	—	5/1999	770	H	000MBSL	250
AD-842	394505	0772320	Alexander	9/24/2001	780	H	000MBSL	300
AD-843	394501	0772319	L. Adams	6/22/1992	750	H	000MBSL	350
AD-844	394500	0772318	Alexander	6/8/1999	750	H	000MBSL	500
AD-845	394456	0772318	Alexander	4/14/1999	710	S	000MBSL	220
AD-846	394453	0772320	Alexander	10/2/1996	680	V	000MBSL	400
AD-847	394453	0772239	Alexander	8/3/1992	550	S	000MBSL	200
AD-848	394453	0772250	Larry Adams	2/8/1993	600	S	000MBSL	175
AD-849	394430	0772228	L. Adams	5/1/1995	560	S	000MTRL	250
AD-850	394447	0772305	Alexander	4/9/1994	660	S	000MBSL	240
AD-851	394451	0772312	Alexander	9/1998	655	S	000MBSL	330
AD-852	394452	0772324	J.F. Harrison	5/1988	725	S	000MBSL	180
AD-853	394428	0772227	Alexander	8/1989	610	S	000MTRL	180
AD-854	394450	0772303	Alexander	10/29/1994	670	S	000MBSL	500
AD-855	394450	0772258	L. Adams	9/10/1993	660	S	000MBSL	350
AD-856	394449	0772251	Alexander	9/1988	620	S	000MBSL	305
AD-857	394425	0772229	Alexander	3/8/1999	660	S	000MTRL	200
AD-858	394423	0772226	Alexander	7/15/1994	640	S	000MTRL	160
AD-859	394447	0772314	Burcker	11/30/1990	720	S	000MBSL	185
AD-860	394445	0772320	Alexander	8/1989	820	S	000MBSL	250
AD-861	394446	0772244	Kohler	5/1995	580	S	000MBSL	200
AD-862	394444	0772255	Alexander	10/1/1993	630	S	000MTRL	500
AD-863	394444	0772316	Alexander	5/19/1999	780	S	000MBSL	580
AD-864	394444	0772323	Alexander	9/24/1998	845	S	000MBSL	440

Table 4. *Records of selected wells and springs, Borough of Carroll Valley, Adams County, Pennsylvania*—*Continued*

Casing		Depth(s) to water-producing zone(s) (feet)	Static water level (feet below land surface)	Date water level measured	Driller reported yield (gal/min)	Specific capacity (gal/min)/ft	Depth to bedrock (feet)	USGS well identification number
Length (feet)	Diameter (inches)							
60	6	195	60	8/12/1995	4	0.03	50	AD-820
40	6	280	107.11	8/15/2001	2	.01	20	AD-821
55	6	140	24.49	8/15/2001	20	.4	45	AD-822
27	6	—	42	8/15/2001	5	—	—	AD-823
40	6	176	65.21	8/15/2001	2.1	.01	30	AD-824
70	6	250	107.04	8/15/2001	3	.03	65	AD-825
—	6	—	73.93	8/15/2001	—	—	—	AD-826
40	6	—	99.85	8/15/2001	3	—	—	AD-827
—	6	—	116.97	8/15/2001	—	—	—	AD-828
72	6	260; 360	168.4	8/15/2001	2	.01	62	AD-829
40	6	200	96.8	8/15/2001	1	<.01	94	AD-830
40	6	265; 360	73.99	8/15/2001	4.6	.02	20	AD-831
55	6	180; 220; 280	64.55	8/15/2001	6	—	40	AD-832
40	6	—	26.55	8/15/2001	10	—	—	AD-833
42	6	140; 340	72.35	8/29/2001	2	.01	30	AD-834
—	6	—	97.2	8/15/2001	—	—	—	AD-835
80	6	200; 460	95.9	8/29/2001	5	—	70	AD-836
91	6	111; 220; 330	68.6	8/15/2001	3.3	.01	75	AD-837
40	6	144; 164; 240	58	8/15/2001	8	.04	20	AD-838
63	6	120; 140; 220	47.8	8/15/2001	10	.11	50	AD-839
—	6	—	4.2	8/29/2001	—	—	—	AD-840
40	6	160; 210	6.85	8/29/2001	8	—	20	AD-841
40	6	105; 240	2.72	1/29/2002	3	.02	20	AD-842
55	6	225	41.7	11/15/2000	4	.03	35	AD-843
40	6	260	53.6	8/15/2001	.5	<.01	20	AD-844
40	6	165	22.4	8/15/2001	25	.36	20	AD-845
62	6	120	1.2	8/15/2001	1	<.01	50	AD-846
54	6	140; 180	40	8/3/1992	8	.1	35	AD-847
42	6	145	43	2/8/1993	3	—	40	AD-848
63	6	100	50	5/1/1995	5	.03	60	AD-849
40	6	140	40	4/9/1994	3	.02	25	AD-850
30	6	300	—	—	1	—	24	AD-851
81	6	98; 172	—	—	30	—	64	AD-852
63	6	158; 168	40	9/1989	40	.67	54	AD-853
40	6	320	60	10/29/1994	.5	<.01	20	AD-854
40	6	240	60	9/10/1993	3	.01	40	AD-855
30	6	200	25	9/1988	1	.01	20	AD-856
60	6	160; 180	20	3/8/1999	20	.25	50	AD-857
80	6	100; 145	60	7/15/1994	15	.25	70	AD-858
48; 108	6; 4	125; 165	125	11/30/1990	13	.52	48	AD-859
21	6	80; 125; 165; 225	70	8/1989	8	.09	10	AD-860
51	6	61; 112; 165	22	5/1995	7	—	60	AD-861
60	6	260; 320	40	10/1/1993	1	<.01	50	AD-862
40	6	200; 430	116	5/19/1999	1	<.01	20	AD-863
47	6	300; 360	60	9/24/1998	1	<.01	40	AD-864

Table 4. *Records of selected wells and springs, Borough of Carroll Valley, Adams County, Pennsylvania—Continued*

USGS well identification number	Location		Driller	Date completed	Altitude of land surface (feet)	Topo-graphic setting	Hydrogeologic unit	Depth of well (feet)
	Latitude	Longitude						
AD-865	394446	0772326	Alexander	11/5/1992	800	S	000MBSL	200
AD-866	394441	0772322	Alexander	2/1988	880	H	000MBSL	475
AD-867	394441	0772321	Alexander	10/27/1998	875	H	000MBSL	600
AD-868	394440	0772318	Alexander	11/1984	850	S	000MBSL	250
AD-869	394440	0772318	Alexander	11/1984	850	S	000MBSL	250
AD-870	394441	0772246	L. Adams	8/11/1994	640	S	000MBSL	250
AD-871	394439	0772254	Alexander	2/21/1997	670	S	000MBSL	260
AD-872	394439	0772257	Alexander	8/1989	675	S	000MTRL	120
AD-873	394439	0772301	Alexander	9/24/1991	680	S	000MTRL	325
AD-874	394436	0772316	Alexander	4/15/2001	850	S	000MTRL	600
AD-875	394436	0772259	Alexander	8/1990	805	S	000MTRL	330
AD-876	394438	0772243	L. Adams	2/1/1994	675	S	000MBSL	300
AD-877	394435	0772300	Alexander	7/25/1996	750	S	000MTRL	300
AD-878	394434	0772303	Alexander	9/20/1994	720	W	000MTRL	300
AD-879	394431	0772251	Alexander	11/1990	800	H	000MBSL	530
AD-880	394429	0772248	Alexander	2/23/1993	790	H	000MBSL	400
AD-881	394427	0772241	Alexander	5/9/1992	740	S	000MBSL	265
AD-882	394432	0772236	Alexander	9/1989	670	S	000MTRL	300
AD-883	394433	0772324	Alexander	11/10/1998	840	S	000GRNS	320
AD-884	394431	0772324	Alexander	10/28/1998	820	S	000GRNS	600
AD-885	394436	0772318	Kohler	11/21/1997	840	S	000MBSL	400
AD-886	394433	0772318	Alexander	3/13/1998	810	S	000MBSL	360
AD-887	394424	0772319	Alexander	1/7/1997	700	S	000MBSL	260
AD-888	394423	0772337	Reichart	6/28/1995	640	W	000MBSL	500
AD-889	394421	0772338	Alexander	3/3/1993	610	W	000GRNS	405
AD-890	394426	0772336	Alexander	5/1989	660	W	000MBSL	535
AD-891	394427	0772336	Alexander	8/6/1997	690	S	000MBSL	460
AD-892	394436	0772325	Alexander	5/17/2000	850	S	000MBSL	750
AD-893	394435	0772327	Alexander	10/7/1995	825	S	000MBSL	600
AD-894	394429	0772331	Alexander	12/1988	730	S	000MBSL	535
AD-895	394426	0772329	Alexander	9/12/1995	740	S	000MBSL	400
AD-896	394427	0772324	Alexander	11/9/1998	790	S	000MBSL	400
AD-897	394539	0772333	Alexander	5/1989	740	S	000MBSL	250
AD-898	394533	0772340	Alexander	4/25/1991	800	S	000MBSL	425
AD-899	394533	0772349	Alexander	5/1988	840	S	000MBSL	145
AD-900	394536	0772348	Alexander	9/1989	840	S	000MBSL	105
AD-901	394544	0772346	L. Adams	4/1989	830	S	000MBSL	125
AD-902	394547	0772345	Alexander	10/16/1992	840	S	000MBSL	260
AD-903	394548	0772345	Alexander	8/6/1996	840	S	377LUDN	120
AD-904	394551	0772343	Alexander	6/1988	850	S	377LUDN	145
AD-905	394551	0772341	Alexander	4/3/2000	840	S	377LUDN	160
AD-906	394556	0772339	Alexander	11/19/1997	800	S	377WVRN	200
AD-907	394550	0772340	Alexander	12/1989	820	S	000MBSL	85
AD-908	394426	0772415	Alexander	11/1987	620	W	000GRNS	380
AD-909	394434	0772434	Alexander	6/10/1996	660	S	000MBSL	660

Table 4. *Records of selected wells and springs, Borough of Carroll Valley, Adams County, Pennsylvania—Continued*

Casing		Depth(s) to water-producing zone(s) (feet)	Static water level (feet below land surface)	Date water level measured	Driller reported yield (gal/min)	Specific capacity (gal/min)/ft	Depth to bedrock (feet)	USGS well identification number
Length (feet)	Diameter (inches)							
52	6	120; 182	60	11/5/1992	12	0.15	40	AD-865
21	6	230; 300	25	2/1988	2.5	.01	5	AD-866
20	6	360	200	10/27/1998	.92	<.01	—	AD-867
25	6	60; 70	30	11/1984	.5	<.01	10	AD-868
23	6	60; 70; 130	30	11/1984	1	.01	16	AD-869
60	6	240	50	8/11/1994	1.5	—	60	AD-870
63	6	90; 240	60	2/21/1997	3	.02	50	AD-871
46	6	90	15	8/1989	12	.2	40	AD-872
42	6	60; 81	40	9/24/1991	2	.01	31	AD-873
40	6	—	280	4/15/1994	.03	<.01	20	AD-874
40	6	110	20	8/1990	2	.01	30	AD-875
42	6	285	45	2/1/1994	4	.02	30	AD-876
21	6	150; 260	40	7/25/1996	5	.03	10	AD-877
30	6	80; 140	40	9/20/1994	3	.02	30	AD-878
21	6	—	90	11/1990	.3	<.01	8	AD-879
20	6	200	40	2/23/1993	.75	<.01	10	AD-880
60	6	140; 240	50	5/9/1992	8	.06	45	AD-881
21	6	—	—	—	.14	<.01	12	AD-882
20	6	100	110	11/10/1998	.25	<.01	—	AD-883
20	6	300	200	10/28/1998	.1	<.01	—	AD-884
32	6	168	50	11/21/1997	.75	<.01	18	AD-885
54	6	115; 260	40	3/13/1998	2	.01	40	AD-886
21	6	230	30	1/7/1997	6	.09	4	AD-887
33	6	139; 473	20	6/28/1995	4	—	14	AD-888
—	6	—	30	3/3/1993	1.5	<.01	—	AD-889
68	6	515	40	5/1989	1	<.01	62	AD-890
60	6	420	20	8/6/1997	1	<.01	50	AD-891
40	6	140; 340; 500	78	5/20/2000	2	<.01	10	AD-892
—	6	—	—	—	.25	<.01	—	AD-893
25	6	200; 505	100	12/1988	4	.02	20	AD-894
20	6	290	60	9/12/1995	.75	<.01	6	AD-895
20	6	310	200	11/9/1998	6	.12	5	AD-896
21	6	140	20	5/1989	3	.02	0	AD-897
40	6	400	10	4/25/1991	2.5	.01	10	AD-898
44	6	65; 110	15	5/1988	15	.23	38	AD-899
42	6	50; 80; 90	20	9/1989	150	7.5	30	AD-900
115	6	120	10	4/1989	45	.9	110	AD-901
88	6	200	15	10/16/1992	3	.02	77	AD-902
84	6	90	30	8/6/1996	30	.86	108	AD-903
90	6	120	20	6/1988	18	.45	85	AD-904
74	6	115; 140	30	4/3/2000	20	.4	63	AD-905
52	6	135	20	11/19/1997	3	.02	40	AD-906
43	6	50; 65	21	12/1989	60	6.67	35	AD-907
40	6	160; 180	30	11/1987	2	<.01	30	AD-908
40	6	200	55	6/10/1996	2	.01	25	AD-909

Table 4. Records of selected wells and springs, Borough of Carroll Valley, Adams County, Pennsylvania—Continued

USGS well identification number	Location: Latitude	Location: Longitude	Driller	Date completed	Altitude of land surface (feet)	Topo-graphic setting	Hydrogeologic unit	Depth of well (feet)
AD-910	394439	0772437	Alexander	10 / 1988	690	S	000MBSL	210
AD-911	394444	0772438	Alexander	3 / 30 / 2000	720	S	000MBSL	650
AD-912	394450	0772432	Alexander	7 / 18 / 1997	750	S	000MBSL	380
AD-913	394451	0772432	Alexander	5 / 1 / 1996	760	S	000MBSL	360
AD-914	394452	0772430	Alexander	5 / 29 / 1997	770	S	000MBSL	460
AD-915	394446	0772431	Alexander	8 / 1989	760	S	377LUDN	430
AD-916	394436	0772425	Alexander	5 / 24 / 1996	750	W	000MBSL	600
AD-917	394437	0772433	Alexander	8 / 1990	690	S	377LUDN	275
AD-918	394436	0772422	Alexander	10 / 5 / 1996	700	W	000MBSL	220
AD-919	394434	0772422	Alexander	2 / 12 / 1997	680	W	000MBSL	240
AD-920	394430	0772422	Alexander	5 / 1990	750	S	000MBSL	280
AD-921	394429	0772418	Alexander	11 / 2 / 1998	650	S	000GRNS	380
AD-922	394432	0772418	Alexander	9 / 18 / 1995	670	S	000GRNS	400
AD-923	394432	0772420	Alexander	11 / 1989	680	S	000GRNS	312
AD-924	394435	0772420	Alexander	10 / 24 / 1995	700	S	000GRNS	300
AD-925	394435	0772418	Alexander	5 / 1990	700	S	000GRNS	292
AD-926	394437	0772423	Alexander	3 / 10 / 1998	750	W	000MBSL	200
AD-927	394439	0772421	Alexander	11 / 6 / 1995	750	W	000GRNS	280
AD-928	394439	0772416	Alexander	6 / 12 / 1996	750	S	000MBSL	225
AD-929	394432	0772412	Reichart	4 / 22 / 1992	660	W	000MBSL	175
AD-930	394444	0772422	Reichart	1 / 7 / 1993	820	S	000MBSL	200
AD-931	394448	0772427	Alexander	11 / 1989	820	S	377LUDN	470
AD-932	394452	0772429	Alexander	8 / 11 / 1995	780	S	000MBSL	300
AD-933	394456	0772425	J.F. Harrison	3 / 16 / 2000	830	S	000GRNS	623
AD-934	394418	0772231	Harley	6 / 27 / 2000	660	S	000MTRL	225
AD-936	394421	0772248	Alexander	6 / 3 / 1996	730	S	000MBSL	200
AD-937	394424	0772245	Alexander	12 / 24 / 1997	760	H	000MBSL	300
AD-938	394426	0772241	Alexander	4 / 1988	750	S	000MBSL	165
AD-939	394426	0772244	Reichart	9 / 1989	770	H	000MBSL	175
AD-940	394426	0772246	Alexander	12 / 23 / 1997	770	H	000MBSL	140
AD-941	394424	0772248	J.F. Harrison	1 / 1991	750	S	000MTRL	373
AD-942	394429	0772309	Alexander	9 / 11 / 1997	770	S	000MTRL	400
AD-943	394423	0772300	Alexander	9 / 16 / 1996	750	S	000MBSL	240
AD-944	394423	0772254	Alexander	10 / 28 / 1996	710	W	000MBSL	380
AD-945	394424	0772256	Alexander	5 / 25 / 1991	740	S	000MBSL	370
AD-946	394424	0772253	Alexander	8 / 28 / 1997	720	W	000MBSL	340
AD-947	394426	0772250	Alexander	12 / 1989	750	W	000MBSL	550
AD-948	394427	0772247	Reichart	9 / 1990	770	H	000MBSL	500
AD-949	394427	0772247	Reichart	10 / 1990	770	H	000MBSL	175
AD-950	394428	0772250	Alexander	11 / 15 / 1996	780	H	000GRNS	620
AD-951	394429	0772254	Alexander	1 / 1986	810	H	000MBSL	410
AD-952	394430	0772259	Alexander	6 / 20 / 1998	820	H	000MTRL	500
AD-953	394430	0772300	Alexander	6 / 18 / 1998	820	H	000MTRL	500
AD-955	394502	0772417	Alexander	8 / 3 / 1996	900	S	000GRNS	620
AD-956	394501	0772415	Alexander	9 / 14 / 2000	895	H	000MBSL	640

Table 4. *Records of selected wells and springs, Borough of Carroll Valley, Adams County, Pennsylvania*—*Continued*

Casing: Length (feet)	Casing: Diameter (inches)	Depth(s) to water-producing zone(s) (feet)	Static water level (feet below land surface)	Date water level measured	Driller reported yield (gal/min)	Specific capacity (gal/min)/ft	Depth to bedrock (feet)	USGS well identification number
42	6	—	40	10/1988	4	0.03	35	AD-910
40	6	200; 430	32	3/30/2000	3.75	.02	25	AD-911
48	6	340; 360	80	7/18/1997	30	.3	35	AD-912
60	6	330	60	5/1/1996	8	.06	45	AD-913
65	6	445	60	5/29/1997	60	1	55	AD-914
63	6	200; 400	40	8/1989	6	.05	57	AD-915
42	6	560	60	5/24/1996	2	<.01	30	AD-916
25	6	105	55	8/1990	1	.01	15	AD-917
42	6	205	40	10/5/1996	30	.6	28	AD-918
43	6	225	60	2/12/1997	7	.06	27	AD-919
41	6	265	30	5/1990	12	.4	34	AD-920
40	6	360	60	11/2/1998	8	.06	20	AD-921
40	6	265	60	9/18/1995	1	<.01	25	AD-922
21	6	260; 280	50	11/1989	2	.01	14	AD-923
40	6	240; 255	40	10/24/1995	5	.03	25	AD-924
40	6	260	40	5/1990	3	.04	32	AD-925
42	6	110; 180	20	3/10/1998	9	.11	30	AD-926
63	6	105; 255	40	11/6/1995	1.5	.01	50	AD-927
21	6	155	50	6/12/1996	2	.02	8	AD-928
21	6	41; 55; 75	5	4/22/1992	6	—	6	AD-929
21	6	57; 85	33	1/7/1993	5	—	8	AD-930
21	6	450	140	11/1989	4	.03	10	AD-931
60	6	270	60	8/11/1995	20	.67	50	AD-932
80	6	430	146	3/16/2000	1.5	.02	59	AD-933
53	6	210	80	6/27/2000	20	—	45	AD-934
42	6	80; 100	60	6/3/1996	5	.05	20	AD-936
40	6	200; 260	40	12/24/1997	1.5	.01	30	AD-937
21	6	140	20	4/1988	12	.15	10	AD-938
21	6	91; 114; 140	48	9/1989	12	—	4	AD-939
40	6	110; 120	60	12/23/1997	12	.25	30	AD-940
40	6	338; 370	80	1/1991	5	.02	18	AD-941
40	6	200; 330	40	9/11/1997	4	.03	10	AD-942
20	6	200	40	9/16/1996	3	.02	10	AD-943
21	6	160	40	10/28/1996	.5	<.01	5	AD-944
27	6	260	40	5/25/1991	1	<.01	15	AD-945
23	6	150	50	8/28/1997	1	<.01	1	AD-946
21	6	21	80	12/1989	.23	<.01	16	AD-947
21	6	55; 432	130	9/1990	1.25	—	13	AD-948
21	6	44; 69; 107; 142	35	10/1990	6.5	—	9	AD-949
27	6	—	60	11/15/1996	.33	<.01	10	AD-950
21	6	260	100	1/1986	.5	<.01	5	AD-951
28	6	260	100	6/20/1998	1	<.01	10	AD-952
48	6	300	100	6/18/1998	1	<.01	35	AD-953
21	6	300	60	8/3/1996	.33	<.01	5	AD-955
40	6	210; 350	76.4	8/15/2001	1.3	<.01	20	AD-956

Table 4. *Records of selected wells and springs, Borough of Carroll Valley, Adams County, Pennsylvania*—*Continued*

USGS well identification number	Location		Driller	Date completed	Altitude of land surface (feet)	Topo-graphic setting	Hydrogeologic unit	Depth of well (feet)
	Latitude	Longitude						
AD-957	394459	0772417	Alexander	6/26/1996	880	H	000MBSL	600
AD-958	394458	0772418	Alexander	6/1987	880	H	000MBSL	515
AD-959	394453	0772417	Alexander	9/10/1996	830	S	000MBSL	200
AD-960	394448	0772418	Alexander	3/11/1998	850	S	000MBSL	240
AD-961	394448	0772419	Alexander	2/15/1996	860	S	000MBSL	200
AD-962	394446	0772420	Alexander	2/22/2000	840	S	000MBSL	500
AD-963	394444	0772420	Alexander	5/1990	820	S	000MBSL	330
AD-964	394443	0772421	Alexander	4/4/1991	800	W	000MBSL	305
AD-965	394442	0772421	Alexander	4/3/1991	790	S	000MBSL	260
AD-966	394441	0772422	Alexander	11/1990	770	W	000MBSL	300
AD-967	394441	0772419	Alexander	4/10/1992	780	S	000GRNS	200
AD-968	394443	0772415	Alexander	4/12/1996	760	S	000MBSL	400
AD-969	394446	0772406	Alexander	6/4/1998	750	S	000MBSL	400
AD-970	394448	0772406	Alexander	6/1986	770	S	000MBSL	395
AD-971	394454	0772406	Alexander	9/10/1991	770	W	000GRNS	265
AD-972	394504	0772405	Alexander	1/1990	850	S	000MBSL	450
AD-973	394502.4	0772402.1	—	2000	880	S	000MBSL	—
AD-974	394500	0772401	Alexander	8/13/1999	880	S	000MBSL	240
AD-975	394454	0772402	Alexander	10/24/1995	790	S	000MBSL	200
AD-976	394451	0772403	L. Adams	3/28/1997	780	S	000MBSL	175
AD-977	394449	0772402	Alexander	6/5/1995	800	S	000MBSL	220
AD-978	394440	0772403	Alexander	7/24/1997	810	S	000MBSL	500
AD-979	394438	0772400	Alexander	7/1990	820	S	000MBSL	350
AD-980	394442	0772354	J.F. Harrison	6/26/1996	840	S	000MBSL	298
AD-981	394444	0772352	Alexander	6/11/1997	860	S	000MBSL	340
AD-982	394445	0772356	Alexander	7/1/1996	870	H	000GRNS	400
AD-983	394442	0772357	Alexander	2/15/1991	860	S	000MBSL	205
AD-984	394441	0772359	Alexander	8/24/1995	840	S	000MBSL	240
AD-985	394446	0772358	Alexander	9/18/1991	850	S	000GRNS	400
AD-986	394446	0772358	Alexander	4/6/2001	850	S	000GRNS	300
AD-987	394450	0772356	Alexander	4/12/2000	850	S	000MBSL	260
AD-988	394446	0772347	Alexander	7/1990	860	H	000MBSL	465
AD-989	394444	0772344	Alexander	2/1990	860	H	000MBSL	270
AD-990	394444	0772340	Alexander	4/22/1992	880	H	000MBSL	200
AD-991	394444	0772341	Alexander	1/14/1997	880	H	000MBSL	500
AD-992	394443	0772339	Alexander	1/11/1997	880	H	000MBSL	500
AD-993	394442	0772339	Alexander	1/21/1998	880	H	000MBSL	400
AD-994	394441	0772333	Alexander	7/1989	850	H	000MBSL	395
AD-995	394458	0772351	Alexander	7/1993	900	H	000MBSL	715
AD-996	394452	0772354	Alexander	8/9/1995	850	S	000MBSL	300
AD-997	394453	0772353	Alexander	4/13/2000	860	S	000MBSL	400
AD-998	394451	0772348	Alexander	10/23/1995	900	H	000GRNS	180
AD-999	394447	0772338	Alexander	3/10/1997	860	H	000MBSL	380
AD-1000	394446	0772336	Alexander	9/29/1992	850	H	000MBSL	400
AD-1001	394448	0772333	Alexander	8/29/1997	810	S	000MBSL	360

Table 4. *Records of selected wells and springs, Borough of Carroll Valley, Adams County, Pennsylvania—Continued*

Casing		Depth(s) to water-producing zone(s) (feet)	Static water level (feet below land surface)	Date water level measured	Driller reported yield (gal/min)	Specific capacity (gal/min)/ft	Depth to bedrock (feet)	USGS well identification number
Length (feet)	Diameter (inches)							
31	6	500	60	6 / 26 / 1996	0.5	<0.01	15	AD-957
21	6	400	60	6 / 1987	1	<.01	10	AD-958
61	6	90; 140	50	9 / 10 / 1996	5	.07	35	AD-959
80	6	115; 210	30	3 / 11 / 1998	6	.03	70	AD-960
42	6	140	30	2 / 15 / 1996	15	.15	30	AD-961
40	6	200; 300; 380	40	2 / 22 / 2000	1.3	<.01	20	AD-962
29	6	165	40	5 / 1990	1.5	.01	23	AD-963
21	6	100; 180	20	4 / 4 / 1991	2	.01	10	AD-964
22	6	125; 240	25	4 / 3 / 1991	8	.06	10	AD-965
21	6	140; 284	—	—	5	—	10	AD-966
26	6	140	30	4 / 10 / 1992	8	.1	16	AD-967
40	6	210	30	4 / 12 / 1996	1	<.01	27	AD-968
40	6	320	62	6 / 4 / 1998	1	<.01	5	AD-969
21	6	185; 360	60	6 / 1986	4	.03	10	AD-970
40	6	180; 240	30	9 / 10 / 1991	3	.02	25	AD-971
100	6	—	70	1 / 1990	1	<.01	90	AD-972
—	6	—	71.3	11 / 16 / 2000	—	—	—	AD-973
67	6	190; 220	50	8 / 13 / 1999	20	.4	55	AD-974
60	6	75; 179	50	10 / 24 / 1995	6	.06	45	AD-975
63	6	135	50	3 / 28 / 1997	6.5	.07	55	AD-976
52	6	205	40	6 / 5 / 1995	2	.01	41	AD-977
34	6	200; 350	80	7 / 24 / 1997	1.5	<.01	20	AD-978
21	6	260	100	7 / 1990	1	.01	4	AD-979
63	6	123; 264; 282	80	6 / 26 / 1996	36	.21	40	AD-980
21	6	260	60	6 / 11 / 1997	2.5	.01	5	AD-981
40	6	365	40	7 / 1 / 1996	15	.1	25	AD-982
42	6	100; 180	40	2 / 15 / 1991	25	.36	20	AD-983
41	6	110; 160	60	8 / 24 / 1995	3	.02	30	AD-984
20	6	370	40	9 / 18 / 1991	3	.01	10	AD-985
40	6	100	25	4 / 6 / 1991	1	<.01	30	AD-986
65	6	110; 180; 250	50	4 / 12 / 2000	6	.04	50	AD-987
60	6	60	40	7 / 1990	1	<.01	50	AD-988
40	6	220; 250	15	2 / 1990	6	.04	34	AD-989
40	6	80; 115; 180	40	4 / 22 / 1992	20	.25	25	AD-990
84	6	130; 380	122.39	8 / 15 / 2001	2	.01	70	AD-991
68	6	300; 420	142	1 / 11 / 1997	2	.01	55	AD-992
40	6	100; 260	60	1 / 21 / 1998	3	.01	10	AD-993
42	6	350	80	7 / 1989	3	.01	30	AD-994
20	6	265	—	—	0	0	6	AD-995
53	6	240	60	8 / 9 / 1995	6	.04	40	AD-996
40	6	240; 340	40	4 / 13 / 2000	5	.04	25	AD-997
40	6	65; 85	40	10 / 23 / 1995	6	.1	15	AD-998
44	6	140; 250	30	3 / 10 / 1997	6	.04	30	AD-999
40	6	200	80	9 / 29 / 1992	1	<.01	25	AD-1000
60	6	110; 290	45	8 / 29 / 1997	2	.01	50	AD-1001

Table 4. *Records of selected wells and springs, Borough of Carroll Valley, Adams County, Pennsylvania—Continued*

USGS well identification number	Location: Latitude	Location: Longitude	Driller	Date completed	Altitude of land surface (feet)	Topo-graphic setting	Hydrogeologic unit	Depth of well (feet)
AD-1002	394448	0772334	Alexander	8 / 30 / 1997	820	S	000MBSL	260
AD-1003	394452	0772343	Alexander	12 / 1984	880	S	000MBSL	189
AD-1004	394455	0772345	Alexander	5 / 14 / 1996	900	H	000MBSL	360
AD-1005	394454	0772343	Alexander	5 / 12 / 1997	880	S	000GRNS	280
AD-1006	394451	0772336	Alexander	3 / 26 / 1996	800	S	000MBSL	380
AD-1007	394523	0772333	Alexander	2 / 1989	840	S	000MBSL	168
AD-1008	394521	0772328	Alexander	2 / 26 / 1999	830	S	000MBSL	500
AD-1009	394519	0772329	Alexander	4 / 1987	840	S	000MBSL	208
AD-1011	394517	0772343	Alexander	8 / 1987	900	S	000MBSL	425
AD-1012	394517	0772347	Alexander	3 / 1989	910	S	000MBSL	250
AD-1013	394512	0772336	Alexander	7 / 1989	880	S	000GRNS	410
AD-1014	394510	0772359	Alexander	8 / 17 / 1991	940	S	000MBSL	345
AD-1015	394508	0772351	Alexander	5 / 13 / 1992	950	H	000MBSL	340
AD-1016	394509	0772353	Alexander	9 / 23 / 1998	950	H	000MBSL	320
AD-1017	394510	0772356	Alexander	3 / 16 / 1992	960	H	000MBSL	260
AD-1018	394511	0772347	Alexander	6 / 5 / 1995	970	S	000MBSL	600
AD-1019	394509	0772346	Alexander	11 / 14 / 1994	950	H	000MBSL	400
AD-1020	394511	0772343	Alexander	8 / 1989	930	S	000MBSL	312
AD-1021	394509	0772342	Alexander	10 / 1989	900	S	000GRNS	205
AD-1022	394506	0772348	Alexander	7 / 1984	940	H	000GRNS	208
AD-1023	394505	0772350	Kohler	7 / 7 / 1999	930	H	000GRNS	400
AD-1024	394504	0772352	Alexander	10 / 1989	910	S	000GRNS	350
AD-1025	394507	0772400	Alexander	8 / 1989	910	S	000MBSL	250
AD-1026	394504	0772346	Alexander	2 / 1989	920	H	000MBSL	250
AD-1027	394502	0772346	J.F. Harrison	1 / 1989	910	H	000MBSL	261
AD-1028	394500	0772350	Alexander	8 / 1985	910	H	000MBSL	205
AD-1029	394457	0772342	Alexander	8 / 1984	880	S	000GRNS	209
AD-1030	394508	0772335	Alexander	5 / 16 / 1997	860	S	000MBSL	340
AD-1031	394509	0772333	Alexander	6 / 25 / 1996	860	S	000MBSL	380
AD-1032	394514	0772330	Alexander	2 / 3 / 1998	840	S	000GRNS	200
AD-1033	394516	0772328	Alexander	8 / 26 / 1997	820	S	000GRNS	300
AD-1034	394500	0772337	Alexander	3 / 1990	810	S	000GRNS	145
AD-1035	394454	0772338	J.F. Harrison	7 / 6 / 1989	820	S	000MBSL	517
AD-1036	394506	0772330	Alexander	2 / 14 / 1998	800	S	000GRNS	240
AD-1037	394515	0772312	Alexander	11 / 1990	720	V	000MBSL	290
AD-1038	394513	0772309	Alexander	4 / 29 / 1998	720	S	000MBSL	300
AD-1039	394513	0772325	Alexander	2 / 1 / 1996	790	S	000MBSL	380
AD-1040	394512	0772323	Alexander	9 / 9 / 1998	780	W	000MBSL	140
AD-1041	394512	0772320	Alexander	4 / 1990	770	W	000MBSL	250
AD-1042	394510	0772310	Alexander	2 / 25 / 2000	750	H	000MBSL	600
AD-1043	394509	0772312	Alexander	7 / 7 / 1998	760	H	000MBSL	380
AD-1044	394509	0772315	L. Adams	9 / 1989	770	H	000MBSL	400
AD-1045	394509	0772315	L. Adams	8 / 1989	770	H	000MBSL	400
AD-1046	394510	0772316	Alexander	11 / 25 / 1996	780	H	000MBSL	500
AD-1047	394511	0772324	Alexander	4 / 1990	790	H	000MBSL	300

Table 4. *Records of selected wells and springs, Borough of Carroll Valley, Adams County, Pennsylvania—Continued*

Casing		Depth(s) to water-producing zone(s) (feet)	Static water level (feet below land surface)	Date water level measured	Driller reported yield (gal/min)	Specific capacity (gal/min)/ft	Depth to bedrock (feet)	USGS well identification number
Length (feet)	Diameter (inches)							
40	6	105; 200	50	8/30/1997	1	0.01	30	AD-1002
28	6	40; 140; 170	80	12/1984	10	.2	20	AD-1003
63	6	270	60	5/14/1996	2	.01	52	AD-1004
63	6	180; 260	80	5/12/1997	8	.08	50	AD-1005
40	6	260	10	3/26/1996	1	<.01	28	AD-1006
21	6	45; 90; 145	20	2/1989	10	.25	10	AD-1007
40	6	450	89	2/26/1999	1.5	.01	10	AD-1008
27	6	40; 130	20	4/1987	8	.06	21	AD-1009
42	6	400	60	8/1987	50	.36	35	AD-1011
74	6	80; 170; 230	40	3/1989	6	.05	68	AD-1012
35	6	200	60	7/1989	.5	<.01	30	AD-1013
40	6	140; 200	40	8/17/1991	2	.01	25	AD-1014
40	6	223; 325	40	5/13/1992	4	.02	28	AD-1015
60	6	140; 290	50	9/23/1998	6	.04	50	AD-1016
52	6	100; 150; 240	50	3/16/1992	15	.15	35	AD-1017
40	6	—	50	6/5/1995	.2	<.01	3	AD-1018
40	6	140	50	11/14/1994	1	<.01	30	AD-1019
63	6	280	40	8/1989	3	.02	58	AD-1020
22	6	185	30	10/1989	6	.05	15	AD-1021
21	6	60; 160; 180	35	7/1984	3	.12	7	AD-1022
42	6	285	116	7/7/1999	2.4	.01	28	AD-1023
23	6	280	60	10/1989	2	.01	16	AD-1024
42	6	150; 200	35	8/1980	4	.03	36	AD-1025
21	6	160; 230	20	2/1989	12	.12	5	AD-1026
60	6	97; 184; 237	—	—	12	—	48	AD-1027
60	6	165	30	8/1985	10	.14	50	AD-1028
69	6	75; 160; 180	70	7/1984	4.5	.15	60	AD-1029
21	6	140	30	5/16/1997	2	.01	5	AD-1030
60	6	260	40	6/25/1996	4	.03	45	AD-1031
40	6	130; 180	20	2/3/1998	6	.08	10	AD-1032
45	6	130; 200	30	8/26/1997	4	.03	30	AD-1033
73	6	115	20	3/1990	15	.25	58	AD-1034
82	6	370; 465	50	7/6/1989	1.5	<.01	73	AD-1035
40	6	120; 190	20	2/14/1998	4	.05	30	AD-1036
25	6	119; 169	5	11/1990	8	.07	10	AD-1037
41	6	130; 190	40	4/29/1998	2	.01	30	AD-1038
59	6	85; 310	5	2/1/1996	2	.01	49	AD-1039
40	6	110; 130	30	9/9/1998	15	.25	28	AD-1040
36	6	37; 65; 200; 225	20	4/1990	15	.3	31	AD-1041
73	6	565	30	2/25/2000	1.9	.01	60	AD-1042
40	6	130	30	7/7/1998	1	<.01	30	AD-1043
40	6	50	20	9/1989	.5	<.01	30	AD-1044
40	6	125	45	8/1989	.5	<.01	20	AD-1045
21	6	300	24	11/25/1996	.5	<.01	1	AD-1046
40	6	230	40	4/1990	.5	<.01	33	AD-1047

***Table 4**. Records of selected wells and springs, Borough of Carroll Valley, Adams County, Pennsylvania—Continued*

USGS well identification number	Location: Latitude	Location: Longitude	Driller	Date completed	Altitude of land surface (feet)	Topo-graphic setting	Hydrogeologic unit	Depth of well (feet)
AD-1048	394507	0772320	Alexander	2 / 23 / 1996	780	H	000MBSL	140
AD-1049	394506	0772317	L. Adams	11 / 15 / 1996	780	H	000MBSL	500
AD-1050	394506	0772315	Alexander	12 / 22 / 1995	780	H	000MBSL	300
AD-1051	394505	0772319	Alexander	11 / 5 / 1998	770	H	000MBSL	300
AD-1052	394507	0772326	Alexander	7 / 10 / 1995	780	H	000MBSL	160
AD-1053	394502	0772320	C. Jones	5 / 1986	760	H	000MBSL	205
AD-1054	394457	0772315	Alexander	5 / 15 / 1996	720	S	000MBSL	580
AD-1055	394457	0772317	Alexander	10 / 3 / 1997	720	S	000MBSL	180
AD-1056	394500	0772321	Alexander	8 / 31 / 1994	740	H	000MBSL	100
AD-1057	394456	0772320	Alexander	10 / 3 / 1996	710	S	000MBSL	180
AD-1058	394455	0772326	Alexander	7 / 1990	740	S	000GRNS	475
AD-1060	394448	0772400	Alexander	6 / 15 / 2001	820	S	000MBSL	320
AD-1061	394446	0772355	Alexander	6 / 18 / 2001	880	H	000GRNS	600
AD-1062	394442	0772336	Negley	8 / 2000	870	H	000MBSL	273
AD-1063	394533	0772346	Alexander	8 / 2001	810	W	000MBSL	700
AD-1064	394425	0772224	Alexander	3 / 18 / 1999	530	S	000MTRL	220
AD-1065	394438	0772248	Alexander	5 / 4 / 1994	690	S	000MBSL	320
AD-1066	394435	0772310	Alexander	1 / 12 / 1994	760	W	000MTRL	320
AD-1067	394418	0772318	Alexander	5 / 1989	590	S	000MBSL	535
AD-1074	394429	0772247	Alexander	2 / 23 / 1993	750	H	000MBSL	400
AD-1075	394435	0772324	Alexander	11 / 11 / 1999	830	S	000GRNS	300
AD-1076	394432	0772319	—	1968	790	S	000MBSL	610
AD-1077	394430	0772317	Keyser	1972	780	S	000MBSL	302
AD-1078	394422	0772335	Keyser	1968	640	S	000MBSL	190
AD-1079	394420	0772339	Alexander	10 / 1 / 1994	610	S	000GRNS	400
AD-1080	394426	0772339	Keyser	1968	670	W	000GRNS	300
AD-1081	394426	0772334	—	11 / 3 / 1994	700	S	000MBSL	400
AD-1082	394436	0772332	L. Adams	5 / 31 / 1994	820	S	000GRNS	250
AD-1083	394431	0772328	Eichelberger	12 / 2 / 1998	820	S	000MBSL	625
AD-1084	394545	0772339	L. Adams	5 / 12 / 1995	780	S	000MBSL	200
AD-1085	394544	0772333	Keyser	1968	750	S	000MBSL	280
AD-1086	394435	0772435	Alexander	3 / 17 / 1995	670	S	000MBSL	560
AD-1087	394436	0772432	Reichart	4 / 5 / 1996	690	S	377LUDN	400
AD-1088	394435	0772423	Alexander	2 / 14 / 1995	690	W	000MBSL	220
AD-1089	394433	0772418	Alexander	6 / 2 / 1999	690	S	000GRNS	320
AD-1090	394436	0772418	L. Adams	2 / 7 / 1996	730	S	000GRNS	250
AD-1091	394438	0772417	Alexander	6 / 1 / 1999	750	S	000GRNS	500
AD-1092	394453	0772429	Alexander	6 / 26 / 2001	780	S	000MBSL	340
AD-1093	394418	0772239	Alexander	7 / 1 / 1994	710	S	000MTRL	260
AD-1094	394414	0772228	C. Barber	5 / 13 / 996	640	S	000MTRL	150
AD-1095	394414	0772226	C. Barber	5 / 10 / 1996	620	S	000MTRL	150
AD-1096	394412	0772228	L. Adams	5 / 6 / 1992	600	S	000MTRL	100
AD-1097	394423	0772250	L. Adams	3 / 10 / 993	730	S	000MBSL	400
AD-1098	394420	0772259	Alexander	4 / 6 / 1999	720	S	000MBSL	300
AD-1099	394421	0772301	Alexander	4 / 9 / 1999	750	S	000MBSL	510

Table 4. *Records of selected wells and springs, Borough of Carroll Valley, Adams County, Pennsylvania—Continued*

Casing		Depth(s) to water-producing zone(s) (feet)	Static water level (feet below land surface)	Date water level measured	Driller reported yield (gal/min)	Specific capacity (gal/min)/ft	Depth to bedrock (feet)	USGS well identification number
Length (feet)	Diameter (inches)							
42	6	58; 90; 130	20	2 / 23 / 1996	8	0.13	30	AD-1048
100	6	125; 400	50	11 / 15 / 1996	2	.04	75	AD-1049
25	6	240	—	—	2	—	14	AD-1050
28	6	90; 245	20	11 / 5 / 1998	3	.02	18	AD-1051
42; 155	6; 4	70; 110	20	7 / 10 / 1995	12	.3	32	AD-1052
21	6	165	15	5 / 1986	10	.12	10	AD-1053
21	6	106; 360	20	5 / 15 / 1996	4	.02	2	AD-1054
20	6	108; 170	30	10 / 3 / 1997	30	1	3	AD-1055
29	6	80	20	8 / 31 / 1994	6	.12	17	AD-1056
41	6	76; 150	10	10 / 3 / 1996	6	.07	30	AD-1057
30	6	425	40	7 / 1990	.5	<.01	20	AD-1058
41	6	120; 280;	40	6 / 15 / 2001	12	.07	10	AD-1060
42	6	130; 330	93	6 / 18 / 2001	2.14	.01	5	AD-1061
63	6	—	182	8 / 15 / 2001	10	—	—	AD-1062
40	6	400	43	9 / 5 / 2001	0	0	5	AD-1063
77	6	110; 180	40	3 / 18 / 1999	6	—	65	AD-1064
20	6	100; 140; 240	60	5 / 4 / 1994	3	.02	8	AD-1065
20	6	240	80	1 / 12 / 1994	1.5	.01	8	AD-1066
68	6	515	40	5 / 1989	1	<.01	62	AD-1067
20	6	200	40	2 / 23 / 1993	.75	<.01	10	AD-1074
—	6	150; 160	80	11 / 11 / 1999	2	.03	—	AD-1075
17	6	150	100	1968	0	0	7	AD-1076
29	6	93; 248	47	1972	3	—	28	AD-1077
23	6	73; 108; 178	25	1968	6	—	13	AD-1078
40	6	360	40	10 / 1 / 1994	2	.01	30	AD-1079
41	6	78	60	1968	1	—	30	AD-1080
60	6	240	50	11 / 3 / 1994	1	—	50	AD-1081
60	6	242	40	5 / 31 / 1994	25	—	55	AD-1082
40	6	434; 487	5	12 / 2 / 1998	1.5	—	—	AD-1083
70	6	165	50	5 / 12 / 1995	6	—	60	AD-1084
21	6	240	35	1968	2	—	10	AD-1085
29	6	460; 530	40	3 / 17 / 1995	3.5	.01	19	AD-1086
21	6	72; 245; 332	60	4 / 5 / 1996	2	—	7	AD-1087
40	6	205	80	2 / 14 / 2001	50	.63	28	AD-1088
40	6	305	80	6 / 2 / 1999	20	—	20	AD-1089
65	6	240	75	2 / 7 / 1996	20	—	60	AD-1090
40	6	420; 460	97	6 / 1 / 1999	3.3	.01	20	AD-1091
60	6	295; 298	131	6 / 26 / 2001	8	.12	40	AD-1092
60	6	65; 75	50	7 / 1 / 1994	2	.01	50	AD-1093
87	6	90; 115	65	5 / 13 / 1996	20	—	75	AD-1094
89	6	118	65	5 / 10 / 1996	20	—	77	AD-1095
50	6	80; 89	40	5 / 6 / 1992	20	—	40	AD-1096
48	6	150	50	3 / 10 / 1993	1.5	—	40	AD-1097
20	6	160; 240; 260	60	4 / 6 / 1999	1.5	<.01	3	AD-1098
20	6	450	129	4 / 9 / 1999	1	<.01	2	AD-1099

Table 4. *Records of selected wells and springs, Borough of Carroll Valley, Adams County, Pennsylvania—Continued*

USGS well identification number	Location		Driller	Date completed	Altitude of land surface (feet)	Topo-graphic setting	Hydrogeologic unit	Depth of well (feet)
	Latitude	Longitude						
AD-1100	394426	0772310	L. Adams	5 / 1 / 1992	720	S	000MTRL	300
AD-1101	394422	0772258	Alexander	7 / 26 / 1995	740	S	000MBSL	300
AD-1102	394424	0772257	L. Adams	10 / 6 / 1992	760	S	000MBSL	350
AD-1103	394428	0772303	Alexander	5 / 25 / 1995	800	H	000MBSL	521
AD-1104	394427	0772256	L. Adams	3 / 1 / 1994	790	H	000MBSL	300
AD-1105	394454	0772420	L. Adams	10 / 11 / 1991	880	H	000MBSL	300
AD-1106	394445	0772406	Alexander	9 / 4 / 2001	770	S	000GRNS	560
AD-1107	394502	0772401	Kohler	4 / 28 / 1995	880	S	000MBSL	225
AD-1108	394502	0772405	Alexander	1 / 13 / 1995	860	S	000MBSL	260
AD-1109	394454	0772358	Alexander	5 / 19 / 1995	820	S	000MBSL	300
AD-1110	394453	0772359	Alexander	11 / 3 / 1994	810	S	000MBSL	380
AD-1111	394449	0772403	Alexander	3 / 25 / 1995	790	S	000MBSL	280
AD-1112	394451	0772358	Alexander	4 / 12 / 2000	810	S	000MBSL	260
AD-1113	394437	0772358	Alexander	3 / 8 / 1999	820	S	000MBSL	520
AD-1114	394437	0772358	Alexander	7 / 22 / 1999	820	S	000MBSL	500
AD-1115	394442	0772355	Alexander	3 / 15 / 1994	840	S	000MBSL	400
AD-1116	394447	0772355	L. Adams	1 / 16 / 1995	890	H	000GRNS	300
AD-1117	394442	0772401	L. Adams	2 / 9 / 1993	820	S	000MBSL	175
AD-1118	394448	0772357	Alexander	5 / 19 / 1993	860	S	000MBSL	400
AD-1119	394449	0772356	Alexander	9 / 14 / 1995	860	S	000MBSL	460
AD-1120	394441	0772335	Alexander	4 / 12 / 1999	860	H	000MBSL	360
AD-1121	394453	0772352	Alexander	5 / 3 / 1995	870	H	000MBSL	260
AD-1122	394449	0772343	L. Adams	4 / 28 / 1993	890	H	000MBSL	300
AD-1123	394458	0772351	Alexander	8 / 18 / 1993	900	H	000MBSL	300
AD-1124	394457	0772350	Alexander	8 / 22 / 1993	910	H	000MBSL	320
AD-1125	394519	0772350	Alexander	11 / 21 / 1997	940	S	000MBSL	360
AD-1126	394514	0772354	Alexander	8 / 1985	980	H	000MBSL	205
AD-1127	394511	0772359	Keyser	1972	960	H	000MBSL	320
AD-1128	394507	0772355	Alexander	9 / 6 / 1994	940	H	000MBSL	400
AD-1129	394509	0772403	Alexander	12 / 28 / 1994	920	S	000MBSL	400
AD-1130	394503	0772357	Alexander	4 / 28 / 1993	890	W	000MBSL	280
AD-1131	394517	0772330	Alexander	10 / 30 / 2001	850	S	000GRNS	400
AD-1132	394509	0772331	Abbots	11 / 8 / 1991	840	S	000MBSL	305
AD-1133	394509	0772328	L. Adams	4 / 5 / 1995	820	S	000MBSL	175
AD-1134	394512	0772309	Alexander	9 / 1 / 1999	720	S	000MBSL	380
AD-1135	394510	0772312	Alexander	8 / 31 / 1999	760	H	000MBSL	600
AD-1136	394509	0772319	Alexander	6 / 13 / 2000	780	H	000MBSL	600
AD-1137	394503	0772323	Alexander	2 / 7 / 1995	760	H	000MBSL	400
AD-1138	394459	0772312	Alexander	10 / 11 / 1993	740	S	000MBSL	500
AD-1139	394456	0772312	Alexander	9 / 17 / 1994	700	S	000MBSL	560
AD-1140	394458	0772320	L. Adams	5 / 4 / 1992	730	S	000MBSL	125
AD-1141	394459	0772320	Alexander	9 / 16 / 1994	740	H	000MBSL	160
AD-1142	394459	0772327	Alexander	3 / 30 / 1994	770	S	000MBSL	220
AD-1143	394500	0772329	Alexander	4 / 1987	780	W	000MBSL	100
AD-1144	394456	0772329	Keyser	1972	790	H	000MBSL	402

Table 4. *Records of selected wells and springs, Borough of Carroll Valley, Adams County, Pennsylvania—Continued*

Casing Length (feet)	Casing Diameter (inches)	Depth(s) to water-producing zone(s) (feet)	Static water level (feet below land surface)	Date water level measured	Driller reported yield (gal/min)	Specific capacity (gal/min)/ft	Depth to bedrock (feet)	USGS well identification number
40	6	80; 270	45	5/1/1992	3	—	30	AD-1100
42	6	170	30	7/26/1995	2.5	—	40	AD-1101
40	6	190	45	10/6/1992	2	—	33	AD-1102
44	6	251	50	5/25/1995	1	—	25	AD-1103
40	6	100	40	3/1/1994	1	—	35	AD-1104
60	6	110; 230	30	10/11/1991	2	—	50	AD-1105
40	6	260; 460; 520	30	9/4/2001	1.33	<0.01	20	AD-1106
80	6	111; 210	62	4/28/1995	5	—	62	AD-1107
40	6	140; 200	70	1/13/1995	3	—	28	AD-1108
40	6	190	50	5/19/1995	1.1	<.01	28	AD-1109
27	6	340; 350	60	11/3/1994	7	.05	17	AD-1110
60	6	200; 255	60	3/25/1995	2.5	.02	45	AD-1111
65	6	110; 180; 250	50	4/12/2000	6	—	50	AD-1112
40	6	300	34	3/8/1999	.52	<.01	20	AD-1113
40	6	195; 367	62	7/22/1999	.54	<.01	20	AD-1114
43	6	300	40	3/15/1994	3	—	20	AD-1115
55	6	155	50	1/16/1995	1	—	50	AD-1116
44	6	165	40	2/9/1993	20	—	40	AD-1117
30	6	100; 330	80	5/19/1993	.75	<.01	20	AD-1118
42	6	265	60	9/14/1995	.75	<.01	25	AD-1119
40	6	305	170	4/12/1999	8	.27	20	AD-1120
60	6	120; 243	50	5/3/1995	4	.03	50	AD-1121
40	6	265	50	4/28/1993	3.5	—	36	AD-1122
20	6	160; 230; 285	60	8/18/1993	5	.04	8	AD-1123
20	6	240; 305	65	8/22/1993	10	.07	10	AD-1124
60	6	190; 285	60	11/21/1997	3	.02	50	AD-1125
60	6	165	30	8/1985	10	.14	50	AD-1126
34	6	285	65.5	11/6/2000	4	—	33	AD-1127
60	6	250	48	9/6/1994	1	<.01	45	AD-1128
40	6	160; 380	80	12/28/1994	4	.02	28	AD-1129
40	6	200; 230; 245	40	4/28/1993	5	.04	30	AD-1130
40	6	290	40	10/30/2001	5	.02	20	AD-1131
60	6	—	72	11/8/1991	5	—	50	AD-1132
60	6	165	50	4/5/1995	5	—	56	AD-1133
43	6	300	12	9/1/1999	2.1	—	30	AD-1134
54	6	300	27	8/31/1999	2.1	—	40	AD-1135
40	6	480; 560	44	6/13/2000	2.3	.01	20	AD-1136
40	6	200	7	2/7/1995	1.5	<.01	30	AD-1137
20	6	200; 380	40	10/11/1993	2	.01	10	AD-1138
40	6	—	—	—	—	—	25	AD-1139
40	6	110	30	5/4/1992	15	—	29	AD-1140
33	6	80	20	9/16/1994	5	.08	20	AD-1141
40	6	160	F	3/30/1994	1.5	.01	25	AD-1142
40	6	60; 80	20	4/1987	25	.5	35	AD-1143
21	6	105	10	1972	1	—	4	AD-1144

***Table 4**. Records of selected wells and springs, Borough of Carroll Valley, Adams County, Pennsylvania—Continued*

USGS well identification number	Location		Driller	Date completed	Altitude of land surface (feet)	Topo-graphic setting	Hydrogeologic unit	Depth of well (feet)
	Latitude	Longitude						
AD-1145	394458	0772333	Alexander	9/26/1994	800	H	000MBSL	260
AD-1146	394452	0772333	Alexander	9/10/2001	760	W	000MBSL	500
AD-1147	394453	0772312	Alexander	6/1986	660	W	000MBSL	230
AD-1148	394505	0772338	Alexander	12/1/2001	820	W	000MBSL	300
AD-1149	394512	0772349	Alexander	12/26/2001	960	H	000MBSL	520
AD-1150	394534	0772338	Alexander	9/1/2001	780	S	000MBSL	460
AD-1151	394504.6	0772317.9	Alexander	1/2001	770	H	000MBSL	600
AD-1152	394433	0772309	—	1980	770	S	000MTRL	275
AD-1153	394504	0772414	Alexander	10/2001	910	H	000MBSL	240
AD-SP17	394504	0772326	—	1980	760	W	000GRNS	—
AD-SP18	394511.0	0772408.3	—	1900	910	S	000GRNS	—
AD-SP19	394450.1	0772409.1	—	1980	740	V	000GRNS	—

Table 4. *Records of selected wells and springs, Borough of Carroll Valley, Adams County, Pennsylvania—Continued*

Casing		Depth(s) to water-producing zone(s) (feet)	Static water level (feet below land surface)	Date water level measured	Driller reported yield (gal/min)	Specific capacity (gal/min)/ft	Depth to bedrock (feet)	USGS well identification number
Length (feet)	Diameter (inches)							
20	6	140	40	9/26/1994	1	0.01	10	AD-1145
34	6	140; 340; 460	20	9/10/2001	5	.01	10	AD-1146
50	6	208	40	6/1986	6	.04	44	AD-1147
40	6	110; 220	20	12/1/2001	5	.03	20	AD-1148
20	6	300; 440	101.31	1/16/2002	2	.01	2	AD-1149
20	6	430	19.27	1/16/2002	12	.06	5	AD-1150
40	6	—	35.91	1/28/2002	0	0	20	AD-1151
—	6	—	51.33	8/15/2001	—	—	—	AD-1152
40	6	—	59.75	1/16/2002	15	—	—	AD-1153
—	—	—	—	—	5	—	—	AD-SP17
—	—	—	—	—	5	—	—	AD-SP18
—	—	—	—	—	10	—	—	AD-SP19

APPENDIX A—HYDRAULIC CONDUCTIVITY AND TRANSMISSIVITY

Hydraulic conductivity and transmissivity give an indication of the ability or capacity of an aquifer to transmit water. Hydraulic conductivity (K) is defined as the volume of water that will move in a unit time under a unit hydraulic gradient through a unit area, at the prevailing temperature or K = m / d (Heath, 1983, p. 12). Thus, the units of hydraulic conductivity are those of velocity (or distance divided by time). Note, the factors involved in the definition of hydraulic conductivity include the volume of water (Q) that will move in a unit of time (such as a day) under a unit hydraulic gradient (dh / dl or change in hydraulic head over a horizontal distance). So hydraulic conductivity can also be expressed as:

$$K = Qdl/Adh = [(\text{feet}^3/\text{day}) \times \text{feet}]/(\text{feet}^2 \times \text{feet}) = \text{feet/day} \qquad (1)$$

The transmissivity (T) of an aquifer is equal to the hydraulic conductivity (K) of the aquifer multiplied by the saturated thickness (b) of the aquifer or T = Kb. For this report, the saturated thickness of an aquifer was the length of the well's borehole minus the depth to water. Transmissivity will change considerably if one replaces length of well borehole with the depth of the deepest water-producing zone (640 ft in the metabasalt, fig. 7) or thickness of the geologic unit (greater than 1,000 ft for the metabasalt, table 1).

Hydraulic conductivity and transmissivity were calculated from single-well driller drawdown tests (single-well aquifer or specific-capacity tests) by use of a modified Theis formula (Theis and others, 1963) and are shown in table A1. It should be noted, however, the ideal hydrogeological conditions and theoretical assumptions used by Theis and others (1963) rarely are encountered at a well site. Some major assumptions used to determine hydraulic conductivity and transmissivity from specific capacity tests for this report include: (1) ground-water flow to the open interval of the well is radial, (2) vertical flow is excluded from consideration, (3) no well loss due to turbulence, and (4) the producing unit is of infinite areal extent. It should also be noted that the number of tests presented in table A1 is a much smaller sampling than one would expect from the data presented in table 4. Wells were excluded from analysis if the percentage contributed from borehole storage exceeded 100 percent and if the amount of water reportedly discharged by the driller was less than the amount of water stored in the borehole [(static water level - reported drawdown) x 1.47 gal / ft for 6-in. diameter casing].

Well slug tests provide a quick and inexpensive method of estimating the transmissivity in the immediate vicinity of a well. By conducting these tests at several wells, the spacial distribution of transmissivity and hydraulic conductivity (heterogeneity) can be evaluated. The slug test results (table A2) were conducted by causing a sudden change in water level with a 4-ft long, 4-in. diameter displacement barrel. The barrel was either rapidly sunk into or removed from beneath the water to induce a sudden water-level change. The water-level response was measured with a 15 pounds per square inch (psi) pressure transducer and recorded with a data logger at 5-second intervals. The tests were analyzed by the Bouwer and Rice method (Bouwer, 1989).

Table A1. *Summary of driller drawdown tests (utilizing a storativity of 0.00001) in determining transmissivity and hydraulic conductivity, Borough of Carroll Valley, Adams County, Pennsylvania*

[P10, tenth percentile; P25, twenty-fifth percentile; P75, seventy-fifth percentile; P90, ninetieth percentile; ft/day, foot per day; ft^2/day, foot squared per day; —, not applicable]

Geologic formation	Number of wells	P10	P25	Median	P75	P90	Minimum	Maximum
Transmissivity (ft^2/day[1])								
Weverton Formation	1	—	—	5.18	—	—	5.18	—
Loudoun Formation	5	—	—	101	—	—	5.32	243
metabasalt	131	1.42	3.24	9.49	34.3	96.2	.69	2,340
metarhyolite	12	2.35	3.97	8.72	52.8	66.9	2.18	182
greenstone schist	26	1.79	3.01	6.79	23.9	34.2	.48	108
Hydraulic conductivity (ft/day)								
Weverton Formation	1	—	—	.04	—	—	.04	—
Loudoun Formation	5	—	—	1.18	—	—	.02	6.75
metabasalt	131	.00	.01	.04	.24	.63	.00	47.5
metarhyolite	12	.01	.01	.04	.52	.82	.01	1.55
greenstone schist	26	.00	.01	.03	.14	.23	.00	1.03

[1] Saturated thickness (b) of the aquifer is calculated as the length of the borehole of the well (well depth in table 4) minus the depth to water. Transmissivity will change if one uses depth of deepest water-producing zone (640 ft for metabasalt) or estimated thickness of geologic unit (greater than 1,000 ft for metabasalt) instead of the length of the borehole of the well.

Table A2. *Summary of U.S. Geological Survey slug tests and driller drawdown tests in determining transmissivity of the metabasalt, Borough of Carroll Valley, Adams County, Pennsylvania*

[ft^2/day, foot squared per day; —, not applicable]

Well	Transmissivity (ft^2/day)[1]	
	U.S. Geological Survey slug test	Driller drawdown test
AD-774	25	—
AD-806	42	13.89
AD-808	20	—
AD-818	2	1.17
AD-836	87	—
AD-837	17	2.52
AD-842	9	4.26
AD-846	4	—
AD-1060	188	19.14
AD-1062	120	—
AD-1063	4	—
AD-1148	90	6.46
AD-1149	27	1.66
AD-1153	85	—

[1] Saturated thickness (b) of the aquifer is calculated as the length of the borehole of the well (well depth in table 4) minus the depth to water. Transmissivity will change if one uses depth of deepest water-producing zone (640 ft for metabasalt) or estimated thickness of geologic unit (greater than 1,000 ft for metabasalt) instead of the length of the borehole of the well.

APPENDIX B—BOREHOLE GEOPHYSICAL LOGS

Borehole geophysical logs provide information on location and orientation of fractures, water-producing and water-receiving zones, intervals of vertical borehole flow, quantification of borehole flow, lithologic correlation, and data on well construction. The subsurface information that can be determined using borehole geophysics and the geophysical methods employed are summarized in the following table.

Borehole geophysical logs and applicable subsurface information

[A, acoustic televiewer log; C, caliper log; G, natural gamma log; R, single-point resistance log; T, temperature log; V, heatpulse flowmeter]

Borehole geophysical log	Subsurface information
A, C	Location and orientation of fractures and water-producing zones
R, T	Location of water-producing and water-receiving zones
T, V	Intervals of vertical borehole flow
V	Quantification of borehole flow
G, R	Lithologic correlation
C, G	Casing length
C	Borehole diameter

The acoustic televiewer is a sonic imaging tool that scans the borehole wall with an acoustic beam. The reflected acoustic waves are recorded digitally on a portable computer, and images of the wave's transit time and amplitude are produced. The logs are corrected for magnetic orientation, magnetic declination (true north), and borehole deviation from vertical by the logging software. Fractures are detected by longer transit times and decreased signal amplitudes. Because the returned data are oriented to true north and corrected for borehole deviation from vertical, strike and dip for each fracture or bedding plane can be determined. The acoustic televiewer can be used in 6- to 9-in. boreholes.

Caliper logs record the average borehole diameter, which may be related to fractures, lithology, or drilling methods. Caliper logs can be used to identify fractures and possible water-producing or water-receiving zones and correct other geophysical logs for changes in borehole diameter. They also can be correlated with fluid-temperature logs and heatpulse flowmetering to identify fractures and water-producing and water-receiving zones.

The natural-gamma or gamma log measures the natural-gamma radiation (photons) emitted from all rocks. The most common emitters of gamma radiation are uranium-238, thorium-232, their daughter elements, and potassium-40. These radioactive elements are concentrated in clays by adsorption, precipitation, and ion exchange. Fine-grained sediments such as shale or siltstone usually emit more gamma radiation than sandstone, limestone, or dolomite. The gamma log can be run in or out of water or casing. However, casing does reduce the gamma response. The gamma log is used to correlate geologic units between wells (Keys, 1988).

The single-point-resistance log records the electrical resistance of a formation between the probe in a water filled borehole below casing and an electrical ground at land surface. Generally, electrical resistance increases with formation grain size and decreases with borehole diameter, water-producing fractures, and increasing dissolved-solids concentration of borehole water fluid. The single-point-resistance log is used to corollate geology between wells and may help identify water-producing zones. (Keys, 1988).

Fluid-temperature logs provides a continuous record of the temperature of vertical variation in the water in a borehole. Temperature logs are used to identify water-producing and water-receiving zones and to determine zones of vertical borehole flow. Intervals of vertical borehole flow are characterized by little or no temperature gradient. (Williams and Conger, 1990).

The direction and rate of borehole-water movement was determined by the use of a heatpulse flowmeter. The heatpulse flowmeter operates by heating a small sheet of water between two sensitive thermistors (heat sensors). A measurement of direction and rate is computed when a peak temperature is recorded by one of the thermistors. The range of flow measurement is about 0.01-1.5 gal / min in a 2- to 10-in.-diameter borehole (Conger, 1996).

Some heatpulse-flowmeter measurements may be influenced by (1) poor seal integrity between the borehole and heatpulse flowmeter and (2) contributions of water from storage within the borehole. If the seal between the borehole and flowmeter is not complete, some water can bypass the flowmeter, resulting in measurements of flow that are less than the actual rate. Although the heatpulse flowmeter is a calibrated probe, the data are primarily used as a relative indicator to identify water-producing zones.

Three wells were logged AD-774, AD-808, AD-836. A summary of the depths logged, casing depth, depths to water, and geophysical logs run are presented in table B1.

Table B1. *Wells logged at Borough of Carroll Valley, Adams County, Pennsylvania*

[A, acoustic televiewer; C, caliper; G, natural gamma; R, single-point resistance; T, temperature; V, heatpulse flowmeter; ft bls, feet below land surface]

U.S. Geological Survey well identification number	Depth logged (ft bls)	Depth of casing (ft bls)	Depth to water (ft bls)	Geophysical logs run
AD-774	397	12	72	A, C, G, R, T, V
AD-808	231	19	136	A, C, G, R, T, V
AD-836	502	80	89	A, C, G, R, T, V

WELL AD-774

The caliper log shows the total depth of the borehole is 397 ft and it is cased with 6-in. diameter casing to 12 ft bls (fig. B1). The depth to water at the time of data collection was 72 ft bls. The caliper log shows major fractures at 22-24, 28-29, 31-32, and 50-51 ft bls, minor fractures throughout the open-hole section of the borehole, and a change in drilling bit diameter at 68 ft bls. The natural-gamma log shows increased counts at 91 to 124, 192 to 278, and 333 to 395 ft bls that indicate lithologic changes, probably from metabasalt to metarhyolite. The single-point-resistance log shows major deflections (lower electrical resistance) at 95 to 110, 225, and 245 ft bls. The fluid-temperature log shows changes in slope at 93, 121, 203, 223, 238, and 246 ft bls that correlate to fractures shown on the caliper log and zones of lower electrical resistance on the single-point-resistance logs. Under nonpumping conditions, the heatpulse flowmeter measured upward borehole flow at 112, 134, 150, and 254 ft bls, no flow at 82, 232, 310, 336, and 370 ft bls, and possible lateral flow at 180, 196, and 214 ft bls (table B2). The geophysical logs and the heatpulse-flowmeter data indicate water enters the borehole through fractures at 128, 202, and below 254 ft bls and moves upward. The greatest quantity of water exits the borehole through fractures at 92 to 109 ft bls. A minor quantity of water exits the borehole through a fracture at about 236 ft bls. The borehole geophysical logs indicate also that most water-producing and water-receiving zones are at lithologic contacts.

Table B2. *Summary of heatpulse-flowmeter measurements within borehole AD-774 collected on January 16, 2002, Section B, Borough of Carroll Valley, Adams County, Pennsylvania*

[ft bls, feet below land surface; gal/min, gallon per minute; —, not applicable]

Depth (ft bls)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions	Comments
82	No flow	Not determined	—
112	0.16	Up	—
134	.08	Up	—
150	.07	Up	—
180	Not determined	Not determined	Turbulence, possible lateral flow
196	Not determined	Not determined	Turbulence, possible lateral flow
214	Not determined	Not determined	Turbulence, possible lateral flow
232	No flow	Not determined	—
254	.07	Up	Turbulence, possible lateral flow
310	No flow	Not determined	—
336	No flow	Not determined	—
370	No flow	Not determined	—

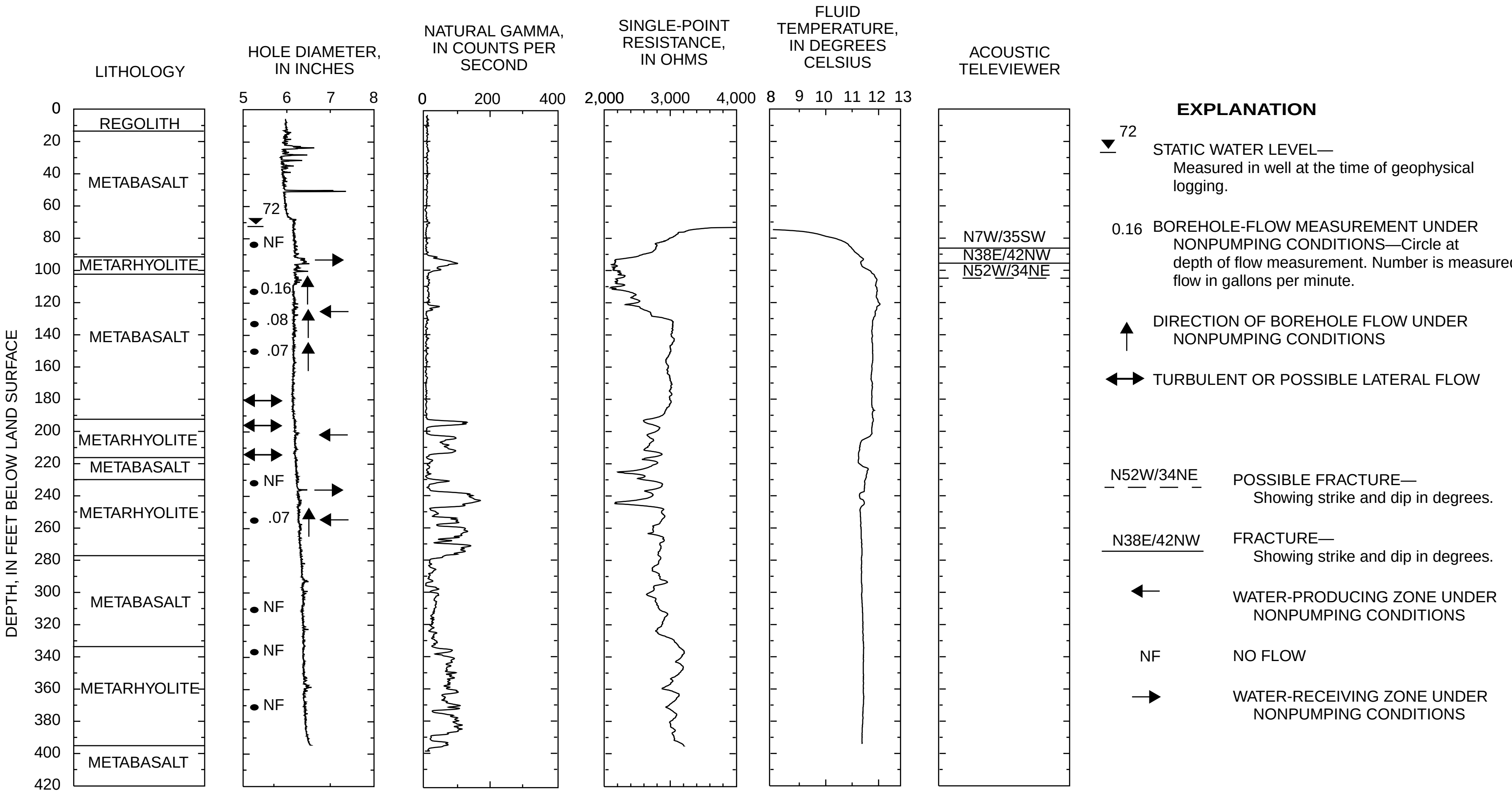

Figure B1. Lithology and borehole geophysical logs and direction of nonpumping flow within borehole AD-774 collected on January 16, 2002, Section B, Borough of Carroll Valley, Adams County, Pennsylvania.

WELL AD-808

The caliper log shows the total depth of the borehole is 231 ft and it is cased with 6-in. diameter casing to 19 ft bls (fig. B2). The depth to water at the time of data collection was 136 ft bls. The caliper log shows a major fracture at 150 to 151 ft bls and minor fractures throughout the open-hole section of the borehole. The natural-gamma log shows increased counts at 179 to 189 and 211 to 230 ft bls that indicate lithologic changes, probably from metabasalt to metarhyolite. The single-point-resistance log shows major deflections (lower electrical resistance) in slope at 150, 180 to 182, 197, 204, and 210 ft bls. The fluid-temperature log shows changes in slope at 181, 184, 197, 207, 212, 221, and 229 ft bls that correlate to minor fractures shown on the caliper log and zones of lower electrical resistance on the single-point-resistance logs. Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 166, 186, 199, and 216 ft bls and possible lateral flow at 146 ft bls (table B3). The geophysical logs suggest that minor quantities of water enter the borehole through fractures at 150 to 151, 195, 204, and 211 ft bls. The borehole geophysical logs indicate also that some water-producing zones occur at lithologic contacts between the metabasalt and metarhyolite.

Table B3. *Summary of heatpulse-flowmeter measurements within borehole AD-808 collected on January 29, 2002, Section P, Borough of Carroll Valley, Adams County, Pennsylvania*

[ft bls, feet below land surface; gal/min, gallon per minute; —, not applicable]

Depth (ft bls)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions	Comments
146	Not determined	Not determined	Turbulence, possible lateral flow
166	No flow	Not determined	—
186	No flow	Not determined	—
199	No flow	Not determined	—
216	No flow	Not determined	—

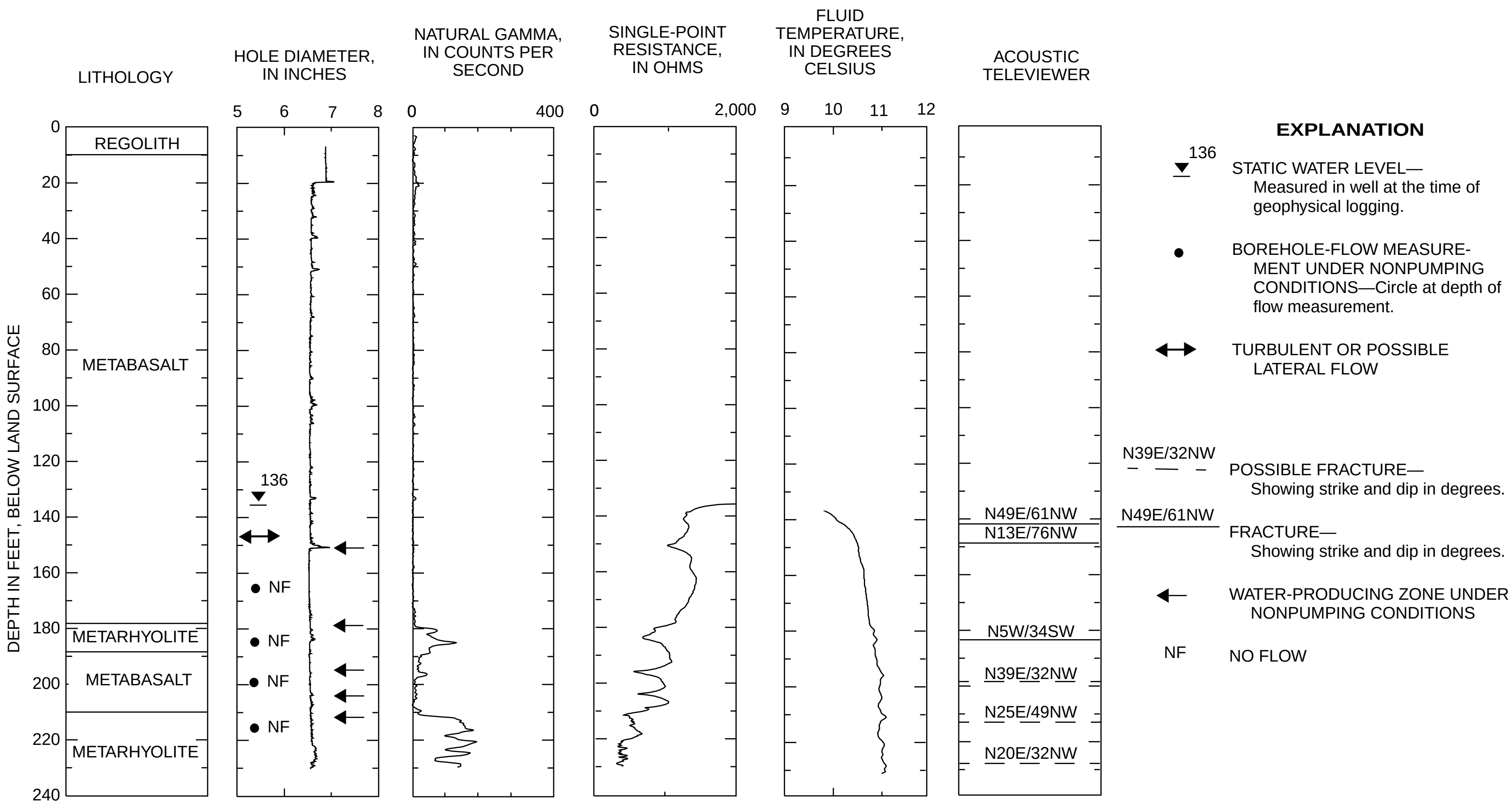

Figure B2. Lithology and borehole geophysical logs and direction of nonpumping flow within borehole AD-808 collected on January 29, 2002, Section P, Borough of Carroll Valley, Adams County, Pennsylvania.

WELL AD-836

The caliper log shows the total depth of the borehole is 502 ft and it is cased with 6-in. diameter casing to 80 ft bls (fig. B3). The depth to water at the time of data collection was 89 ft bls. The caliper log shows fractures at 86, 97, 101, 260, and 380 ft bls and minor fractures at 115, 122, 142 to 144, 182 to 184, 199, and 212 ft bls. The natural-gamma log shows increased counts at 128 to 415 ft bls that indicate lithologic changes, probably from metabasalt to metarhyolite. The single-point-resistance log exhibits a large number of deflections in slope from about 120 to 420 ft bls, which suggests some flow (probably lateral flow). The fluid-temperature log shows a consistent geothermal gradient with only minor interruptions in slope at 222 to 280, 400 to 415, and 470 ft bls that may be due to lateral borehole flow. Under nonpumping conditions, the heatpulse flowmeter measured no borehole flow at 110, 134, 170, 190, 220, 268, 360, 400, 450, 474, and 490 ft bls (table B4).

A submersible pump was placed at 120 ft bls, and the borehole was pumped at an initial rate of 1.1 gal / min. The static water level in the well was 88.75 ft bls. The water level declined 10.05 ft after 46 minutes. Under pumping conditions, the heatpulse flowmeter measured minor upward borehole flow at 134 ft bls and no flow at 170 ft bls. The pumping rate was increased to 2.5 gal / min with a beginning water level of 98.80 ft bls. Under increased pumping conditions, the heatpulse flowmeter measured minor upward borehole flow at 170 ft bls and no flow at 190 ft bls; water levels declined 10.6 ft in 28 minutes. The pumping rate was again increased to 3 gal / min with a beginning water level of 109.40 ft bls; the water level declined 3.75 ft in 14 minutes. Under increased pumping conditions, the heatpulse flowmeter measured minor upward flow at 190 ft bls. The geophysical logs and the heatpulse-flowmeter data indicate a minor quantity of water enters the borehole through fractures at 142, 163, and below 190 ft bls (probably 470 ft bls). When the pumping rate was 1.1 gal / min, 66 percent of the water was produced from above 134 ft bls; at a pumping rate of 2.5 gal / min, 71 percent of the discharge water was produced from above 170 ft bls; at a pumping rate of 3 gal / min, 81 percent of the discharge water was produced from above 190 ft bls.

Table B4. *Summary of heatpulse-flowmeter measurements within borehole AD-836 collected on January 10, 2002, Section WA, Borough of Carroll Valley, Adams County, Pennsylvania*

[ft bls, feet below land surface; gal/min, gallon per minute; —, not applicable]

Depth (ft bls)	Flow rate under nonpumping conditions (gal/min)	Flow direction under nonpumping conditions	Pumping rate (gal/min)
110	No flow	Not determined	—
134	No flow	Not determined	—
170	No flow	Not determined	—
190	No flow	Not determined	—
220	No flow	Not determined	—
268	No flow	Not determined	—
360	No flow	Not determined	—
400	No flow	Not determined	—
450	No flow	Not determined	—
474	No flow	Not determined	—
490	No flow	Not determined	—
Depth (ft bls)	**Flow rate under pumping conditions (gal/min)**	**Flow direction under pumping conditions**	**Pumping rate (gal/min)**
134	0.22	Up	1.1
170	No flow	Not determined	1.1
170	.16	Up	2.5
190	No flow	Not determined	2.5
190	.19	Up	3.0

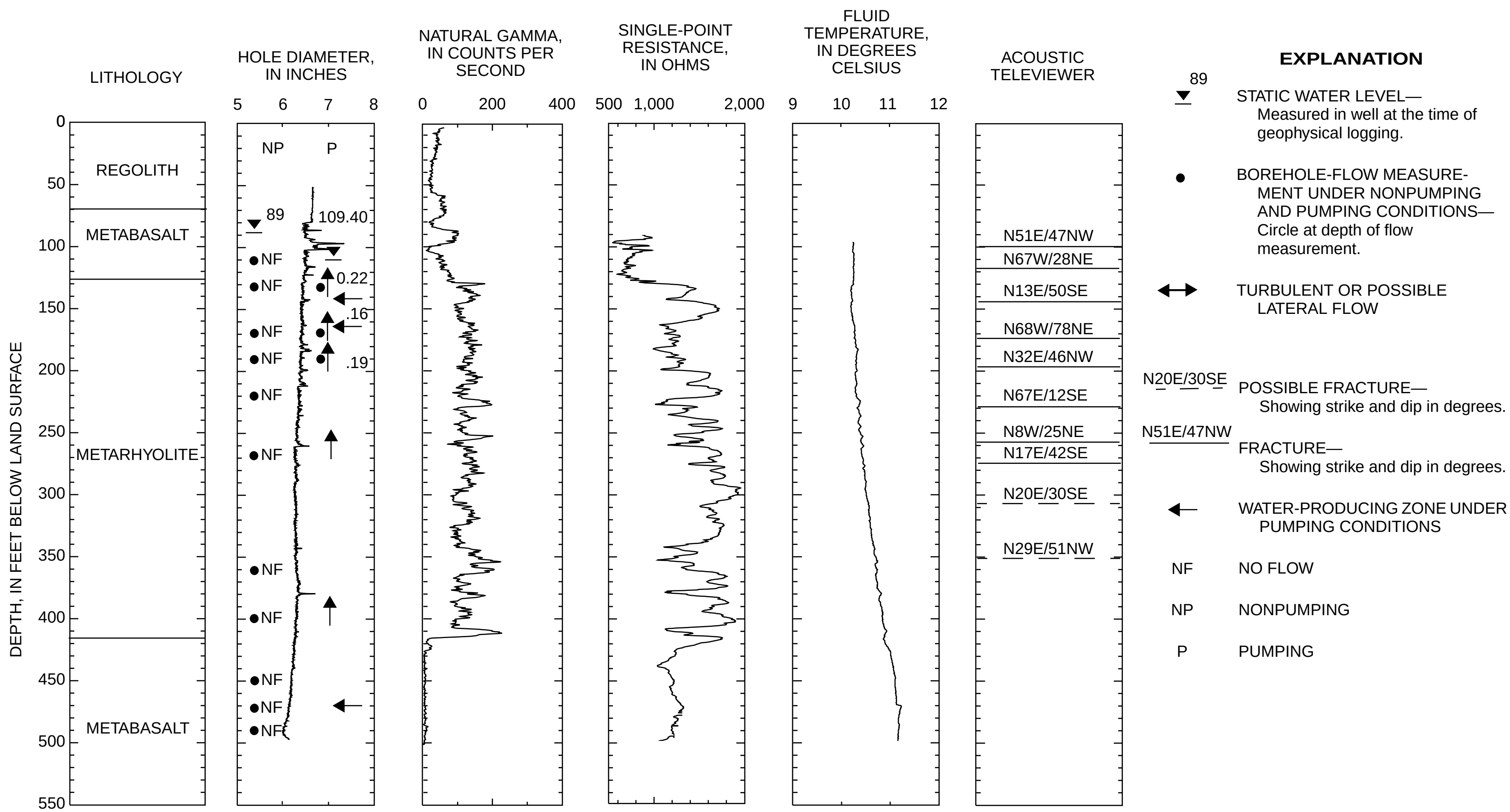

Figure B3. Lithology and borehole geophysical logs and direction of nonpumping and pumping flow within borehole AD-836 collected on January 10, 2002, Section WA, Borough of Carroll Valley, Adams County, Pennsylvania.

APPENDIX C—SOURCE AND SIGNIFICANCE OF SELECTED INDICATORS OF GROUND-WATER QUALITY

[mg/L, milligrams per liter; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level; mL, milliliters; U.S. Environmental Protection Agency, USEPA; N, nitrogen]

Constituent or property	Concentration limits and water-use implications	Implications for ground-water geochemistry
Bromide, dissolved mg/L	Regulatory standards not established for drinking water.	Generally derived from precipitation, dissolution of evaporites or intrusion of brines. The ratio of chloride to bromide can be used to evaluate the origin of dissolved salts in ground water (Davis and others, 1998).
Chloride, dissolved mg/L	The SMCL is 250 mg/L. Water with less than 150 mg/L is suitable for most purposes. A chloride content of more than 250 mg/L is generally objectionable for public supply, and water with a chloride content of more than 350 mg/L is objectionable for most irrigation and industrial uses. Water containing 500 mg/L or more of chloride generally has a disagreeable taste. In large quantities chloride increases the corrosiveness of water.	The most important natural sources of chloride are from sedimentary rocks. Chloride is a rare constituent of non-evaporite rocks. Relatively large amounts of chloride are derived from sewage, industrial wastes, brines and highway deicing practices. Typical concentrations of chloride in ground water range from 10-2,000 mg/L (Cook and Miles, 1980, p. 17).
Total coliform bacteria, colonies/100 mL	The MCL for coliform bacteria in drinking water is zero (or no) total coliform per 100 mL of water.	Total coliform bacteria are indicator organisms that, when present, indicate that there is a possibility, but not a certainty, that disease-causing organisms may also be present in the water due to contamination from human or animal wastes. Coliform bacteria can also occur naturally in the soil, so their presence does not necessarily indicate a sewage-contamination problem or imminent health risk (USEPA, 2000).
Fecal coliform bacteria, colonies /100 mL	The MCL for coliform bacteria in drinking water is zero (or no) total coliform per 100 mL of water.	Fecal coliform bacteria are bacteria whose presence indicates that the water may be contaminated with human or animal wastes. Disease-causing microbes in these wastes can cause diarrhea, cramps, nausea, headaches, or other symptoms. These microbes may pose a special health risk for infants, young children, and people with severely compromised immune systems (USEPA, 2000).
Nitrate, dissolved mg/L as N	Small concentrations of nitrate have no effect on the usefulness of water. Most ground water contains less than 2 mg/L nitrate. Waters containing more than 10 mg/L nitrate may cause methemoglobinemia (blue baby syndrome)- a disease often fatal in infants under 6 months.	Presence of nitrate indicates oxidizing conditions in the aquifer. Decaying organic matter, animal waste, sewage, septic tanks, and fertilizers are principle sources of nitrate. Elevated concentrations are indicative of anthropogenic sources of nitrate (USEPA, 2000).

APPENDIX D—RESULTS OF ANALYSES FOR WASTEWATER COMPOUNDS, ENDOCRINE-DISRUPTING POTENTIAL, AND POSSIBLE COMPOUND USES

Table D1. *Wastewater compounds in selected wells, Borough of Carroll Valley, Adams County, Pennsylvania*

[µg/L, micrograms per liter; <, less than; E, estimated; ND, not detected]

Compound	Minimum reporting level (µg/L)	AD-781 (µg/L)	AD-790 (µg/L)	AD-830 (µg/L)	AD-900 (µg/L)	AD-922 (µg/L)	AD-1098 (µg/L)
1,4-Dichlorobenzene	0.5	ND	ND	ND	ND	ND	ND
Ethynyl estradiol	5	ND	ND	ND	ND	ND	ND
17*beta*-Estradiol	5	ND	ND	ND	ND	ND	ND
1-Methylnaphthalene	.5	ND	ND	ND	ND	ND	ND
2,6-Dimethylnaphthalene	.5	ND	ND	ND	ND	ND	ND
2-Methylnaphthalene	.5	ND	ND	ND	ND	ND	ND
3-*beta*-Coprostanol	2	ND	ND	ND	ND	ND	ND
3-Methyl-1 H-indole (skatol)	1	ND	ND	ND	ND	ND	ND
3-*tert*-Butyl-4-hydroxyanisole (BHA)	5	ND	ND	ND	ND	ND	ND
4-Cumylphenol	1	ND	ND	ND	ND	ND	ND
4-*n*-Octylphenol	1	ND	ND	ND	ND	ND	ND
4-*tert*-Octylphenol	1	ND	ND	ND	ND	ND	ND
5-Methyl-1 H-benzotriazole	2	ND	ND	ND	ND	ND	ND
Acetophenone	.5	ND	ND	ND	ND	ND	ND
Acetyl-hexamethyl-tetrahydonaphthalene (AHTN)	.5	ND	ND	ND	ND	ND	ND
Anthracene	.5	ND	ND	ND	ND	ND	ND
Anthraquinone	.5	ND	ND	ND	ND	ND	ND
Benzo*[a]*pyrene Pyrene	.5	ND	ND	ND	ND	ND	ND
Benzophenone	.5	ND	ND	ND	ND	ND	E 0.02
beta-Sitosterol	2	ND	ND	ND	ND	ND	ND
beta-Stigmastanol	2	ND	ND	ND	ND	ND	ND
Bisphenol A	1	E 0.067	E 0.13	E 0.099	ND	E 0.49	1.2
Bromacil	.5	ND	ND	ND	ND	ND	ND
Bromoform	.5	ND	ND	ND	ND	ND	ND
Caffeine	.5	ND	ND	ND	ND	ND	ND
Camphor	.5	ND	ND	ND	ND	ND	ND
Carbaryl	1	ND	ND	ND	ND	ND	ND
Carbazole	.5	ND	ND	ND	ND	ND	ND
Chlorpyrifos	.5	ND	ND	ND	ND	ND	ND
Cholesterol	2	ND	ND	ND	ND	ND	ND
Cotinine	1	ND	ND	ND	ND	ND	ND
Diazinon	.5	ND	ND	ND	ND	ND	ND
Dichlorvos	1	ND	ND	ND	ND	ND	ND
d-Limonene	.5	ND	ND	ND	ND	ND	ND
Equilenin	5	ND	ND	ND	ND	ND	ND
Estrone	5	ND	ND	ND	ND	ND	ND
Ethynyl estradiol	5	ND	ND	ND	ND	ND	ND
Fluoranthene	.5	ND	ND	ND	ND	ND	ND
Hexahydrohexamethyl-cycloopentabenzopyran (HHCB)	.5	ND	ND	ND	ND	ND	ND
Indole	.5	ND	ND	ND	ND	ND	ND
Isoborneol	.5	ND	ND	ND	ND	ND	ND
Isophorone	.5	ND	ND	ND	ND	ND	ND
Ispropylbenzene (cumene)	.5	ND	ND	ND	ND	ND	ND

Table D1. *Wastewater compounds in selected wells, Borough of Carroll Valley, Adams County, Pennsylvania*—*Continued*

[µg/L, micrograms per liter; <, less than; E, estimated; ND, not detected]

Compound	Minimum reporting level (µg/L)	AD-781 (µg/L)	AD-790 (µg/L)	AD-830 (µg/L)	AD-900 (µg/L)	AD-922 (µg/L)	AD-1098 (µg/L)
Isoquinoline	0.5	ND	ND	ND	ND	ND	ND
Menthol	.5	ND	ND	ND	ND	ND	ND
Metalaxyl	.5	ND	ND	ND	ND	ND	ND
Methyl salicylate	.5	ND	ND	ND	ND	ND	ND
Metolachlor	.5	ND	ND	ND	ND	ND	ND
N,N-diethyl-*meta*-toluamide (Deet)	.5	E 0.13	E 0.067	E 0.076	ND	E 0.22	E 0.42
Naphthalene	.5	ND	ND	ND	ND	ND	ND
Nonylphenol, diethoxy-(total, NPEO2)	5	ND	ND	ND	ND	ND	ND
Octylphenol, diethoxy-(OPEO2)	1	ND	ND	ND	ND	ND	ND
Octylphenol, monoethoxy-(OPEO1)	1	ND	ND	ND	ND	ND	ND
para-Cresol	1	ND	ND	ND	ND	ND	ND
para-Nonylphenol (total)	5	ND	ND	ND	ND	ND	ND
Pentachloropohenol	2	ND	ND	ND	ND	ND	ND
Phenanthrene	.5	ND	ND	ND	ND	ND	ND
Phenol	.5	ND	E .28	E .35	0.68	E .40	E .42
Prometon	.5	ND	ND	ND	ND	ND	ND
Pyrene	.5	ND	ND	ND	ND	ND	ND
Tetrachloroethylene	.5	ND	ND	ND	ND	ND	ND
Tri(2-butoxyethyl) phosphate	.5	ND	ND	ND	ND	E .15	E .086
Tri(2-chloroethyl) phosphate	.5	ND	ND	ND	ND	ND	ND
Tri(dichloroisopropyl) phosphate	.5	ND	ND	ND	ND	ND	ND
Tributyl phosphate	.5	ND	ND	ND	ND	ND	E .1
Triclosan	1	ND	ND	ND	ND	ND	ND
Triethyl citrate (ethyl citrate)	.5	ND	ND	ND	ND	ND	ND
Triphenyl phosphate	.5	E .041	E .064	E .042	ND	E .06	E .12

Table D2. *Wastewater compound endocrine-disrupting potential and possible compound uses* (modified from Zaugg and others, 2002, table 1)

[EDP, endocrine-disrupting potential; K, known, S, suspected; %, percent; —, no data; CP, combustion product; PAH, polycyclicaromatic hydrocarbon; >, greater than; F, fungicide; H, herbicide; I, insecticide; GUP, general use pesticide; WW, wastewater; UV, ultraviolet]

Compound	EDP	Possible compound uses or sources
1,4-Dichlorobenzene	S	Moth repellent, fumigant, deodorant
Ethynyl estradiol	—	Oral contraceptive
17*beta*-Estradiol	—	Estrogen replacement therapy, estrogen metabolite
1-Methylnaphthalene	—	2-5 percent of gasoline, diesel fuel, or crude oil
2,6-Dimethylnaphthalene	—	Present in diesel/kerosene (trace in gasoline)
2-Methylnaphthalene	—	2-5 percent of gasoline, diesel fuel, or crude oil
3-*beta*-Coprostanol	—	Carnivore fecal indicator
3-Methyl-1 H-indole (skatol)	—	Fragrance, stench in feces and coal tar
3-*tert*-Butyl-4-hydroxyanisole (BHA)	K	Antioxidant, general preservative
4-Cumylphenol	K	Nonionic detergent metabolite
4-*n*-Octylphenol	K	Nonionic detergent metabolite
4-*tert*-Octylphenol	K	Nonionic detergent metabolite
5-Methyl-1 H-benzotriazole	—	Antioxidant in antifreeze and deicers
Acetophenone	—	Fragrance in detergent and tobacco, flavor in beverages
Acetyl-hexamethyl-tetrahydonaphthalene (AHTN)	—	Musk fragrance (widespread usage) persistent in ground water
Anthracene	—	Wood preservative, component of tar, diesel, or crude oil, CP
Anthraquinone	—	Manufacturing dye/textiles, seed treatment, bird repellent
Benzo*[a]*pyrene Pyrene	K	Regulated PAH, used in cancer research, CP
Benzophenone	S	Fixative for perfumes and soaps
beta-Sitosterol	—	Plant sterol
beta-Stigmastanol	—	Plant sterol
Bisphenol A	K	Manufacturing polycarbonate resins, antioxidant, flame retardant
Bromacil	—	H (GUP), > 80% noncrop usage on grass/brush
Bromoform	—	WW ozination by-product, military/explosives
Caffeine	—	Beverages, diuretic, very mobile/biodegradable
Camphor	—	Flavor, odorant, ointments
Carbaryl	K	I, crop and garden uses, low persistence
Carbazole	—	I, manufacturing dyes, explosives, and lubricants
Chlorpyrifos	K	I, domestic pest and termite control (domestic use restricted as of 2001)
Cholesterol	—	Often a fecal indicator, also a plant sterol
Cotinine	—	Primary nicotine metabolite
Diazinon	K	I, > 40% nonagricultural usage, ants, flies
Dichlorvos	S	I, pet collars, flies, also a degradate of naled or trichlofon
d-Limonene	—	F, antimicrobial, antiviral, fragrance in aerosols
Equilenin	—	Hormone replacement therapy drug
Estrone	—	Biogenic hormone
Ethynyl estradiol	K	Oral contraceptive
Fluoranthene	—	Component of coal tar and asphalt (only traces in gasoline or diesel fuel), CP
Hexahydrohexamethyl-cycloopentabenzopyran (HHCB)	—	Musk fragrance (widespread usage) persistent in ground water
Indole	—	Pesticide inert ingredient, fragrance in coffee
Isoborneol	—	Fragrance in perfumery, in disinfectants
Isophorone	—	Solvent for lacquer, plastic, oil, silicon, resin
Ispropylbenzene (cumene)	—	Manufacturing phenol/acetone, fuels and paint thinner
Isoquinoline	—	Flavors and fragrances

Table D2. *Wastewater compound endocrine-disrupting potential and possible compound uses* (modified from Zaugg and others, 2002, table 1)—Continued

[EDP, endocrine-disrupting potential; K, known, S, suspected; %, percent; —, no data; CP, combustion product; PAH, polycyclicaromatic hydrocarbon; >, greater than; F, fungicide; H, herbicide; I, insecticide; GUP, general use pesticide; WW, wastewater; UV, ultraviolet]

Compound	EDP	Possible compound uses or sources
Menthol	—	Cigarettes, cough drops, liniment, mouthwash
Metalaxyl	—	H, F (GUP), mildew, blight, pathogens, golf/turf
Methyl salicylate	—	Liniment, food, beverage, UV-absorbing lotion
Metolachlor	—	H (GUP), indicator of agricultural drainage
N,N-diethyl-*meta*-toluamide (Deet)	—	I, urban uses, mosquito repellent
Naphthalene	—	Fumigant, moth repellent, major component (about 10%) of gasoline
Nonylphenol, diethoxy-(total, NPEO2)	K	Nonionic detergent metabolite
Octylphenol, diethoxy-(OPEO2)	K	Nonionic detergent metabolite
Octylphenol, monoethoxy- (OPEO1)	K	Nonionic detergent metabolite
para-Cresol	S	Wood preservative
para-Nonylphenol (total)	K	Nonionic detergent metabolite
Pentachloropohenol	S	H, F, wood preservative, termite control
Phenanthrene	—	Manufacturing explosives, component of tar, diesel fuel, or crude oil, CP
Phenol	—	Disinfectant, manufacturing several products, leachate
Prometon	—	H (noncrop only), applied prior to blacktop
Pyrene	—	Component of coal tar and asphalt (only traces in gasoline or diesel fuel), CP
Tetrachloroethylene	—	Solvent, degreaser, veterinary anthelmintic
Tri(2-butoxyethyl) phosphate	—	Flame retardant
Tri(2-chloroethyl) phosphate	S	Plasticizer, flame retardant
Tri(dichloroisopropyl) phosphate	S	Flame retardant
Tributyl phosphate	—	Antifoaming agent, flame retardant
Triclosan	S	Disinfectant, antimicrobial (concern for acquired microbial resistance)
Triethyl citrate (ethyl citrate)	—	Cosmetics, pharmaceuticals
Triphenyl phosphate	—	Plasticizer, resin, wax, finish, roofing paper, flame retardant